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ON MODERN METHODS
OF
TREATING FRACTURES

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TO MY WIFE

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PREFACE

THE following small book is the outcome of several years of close experimental and clinical study of the problems of fracture treatment. It embodies the work I did on fractures in animals with the assistance of grants which were made to me by the Science Committee of the British Medical Association, and the Hunterian Lecture which I delivered in 1914. But in the present volume I have also endeavoured to examine critically the various methods of fracture treatment which are of practical importance to the modern surgeon, and to indicate the conditions in which one or another ought to be employed.

My principal aims have been two. First, to show that the various methods of treatment should all be brought into our service as occasion requires, instead of being regarded as independent, rival, or mutually destructive systems. And, secondly, to emphasize the necessity for mechanical accuracy and efficiency in dealing with what after all is largely a mechanical problem.

The chapter on Massage and Mobilization has been largely taken from Dr. Mennell's book, and for the figures in that section I am indebted to Dr. Mennell and to Mr. Pirie Watson, to whom I tender my grateful thanks.

The rest of the book represents the author's personal experiments and clinical practice, and there has been no attempt to deal with the vast literature on the subject, because this would have greatly extended the size of the book and confused its main objects set forth above.

I wish to thank Mr. Cecil Joll for having read the proofs and helped me at various stages of the work and the writing; the proprietors of the *Lancet* for permission to use some of the figures illustrating my Hunterian Lecture, and those of the *British Journal of Surgery* for a like courtesy in regard to the chapter on Experimental Observations.

E. W. HEY GROVES.

March, 1916.

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ON MODERN METHODS OF TREATING FRACTURES

CHAPTER I

INTRODUCTORY: THE MYTHS OF YESTERDAY AND THE PROBLEMS OF TO-DAY

THE recognition of fractures, and their treatment, are subjects which have engaged the attention of medical practitioners in all ages, and the evidence of Egyptologists proves that many thousands of years ago broken bones were tied to splints in much the same way as they are to-day.

But in this, as in every other department of science, there has dawned a new era of doubt and scepticism about old axioms on the one hand, and of the building up of new methods, founded upon first principles, on the other. Modern surgery—that is to say, the aseptic system—opened the door to so vast a field of absolutely new ground in dealing with abdominal diseases, that the subject of fractures has perhaps lagged behind, and probably in this department the common practice of to-day is more like that of a thousand years ago than in any other.

Within the last generation, however, pioneers have arisen who have shown that we are not justified in remaining satisfied with the methods of mediæval surgery in the case of broken bones, any more than in that of cerebral or gastric disease.

These men, of whom the most notable are Bardenheuer, Lucas-Championnière, and Sir Arbuthnot Lane, have each begun by a critical observation of the clinical features of their own patients. They have noted in how large a proportion of these, deformity and loss of function result from an application of the commonly received axioms of treatment. And when the statistics of modern industrial insurance are looked into, it is found that these fully bear out this discovery, and we have to face the fact that there is every year an enormous sacrifice of useful limbs and working value as the result of simple injuries.

The x rays, discovered at the end of the last century, quickly gave ready explanation of the most important factor in the causation of this state of affairs, by demonstrating that gross mal-union accompanied most cases of lasting disablement. This demonstration has convinced all except those who wish to remain blind that the basic idea of the old treatment of fractures—viz., that of 'setting' the bone—was largely mythical; and if we once admit that we cannot 'set' a broken bone, then we must be prepared to deal with it in some other way.

THE PRINCIPLES OF THE CLASSICAL TREATMENT OF FRACTURES BY IMMOBILIZATION.

These may be said shortly to consist in : (1) *Setting the bone ;* (2) *Fixing the set bone by splints or plaster ;* (3) *Immobilizing as far as possible the joints above and below the break ;* (4) *Securing immobilization of bone and joints by tightly constricting bandages left in place until firm union has occurred;* and (5) *Allowing the soft parts, skin, nerves, vessels, and muscles, to take care of themselves.*

1. The first of these, the 'setting' of the bone, is in most cases a myth. Three kinds of evidence may be mentioned in support of this statement. First, that of the x rays : when fractures are subjected to skiagraphy as a matter of routine, it is found that in the great majority of the complete fractures, after the most careful manipulations, even with the aid of an anæsthetic, the fragments remain in gross displacement, either because their jagged edges cannot be disentangled from the soft parts, or because their oblique surfaces slip over one another when subjected to the constant pull of muscular spasm. Second, that of operative experience : when a closed fracture is exposed, it is a matter of so much difficulty to fit the broken ends together, that the observer realizes at once how impossible of success must be any attempt to effect this reduction in the dark and with no means of directly controlling the ends of the bone. Third, that of a simple experiment : if a bone be taken and wrapped round with rags and tow to about the thickness of the limb, and the bone be then completely broken across, its ends separated from one another, and an attempt then made to interlock the broken fragments, this will be found to be impossible in most cases. If the jagged ends can be made to catch,

it will usually be found that they have caught in their meshes some of the surrounding packing. And in this experiment there is nothing to represent the never-tiring pull of the muscles.

2. The second principle of the classical treatment, viz., that of fixation of the 'set' bone, will, of course, quite fail if the bone has not been set. The tying on of two splints, or the application of plaster, can never serve to immobilize the bone if its broken ends are not firmly caught one against the other.

3. The third principle, that of fixing the joints above and below the fracture, is in reality a recognition of the difficulty of firmly holding the bone itself; furthermore, this is a counsel which can only be carried out in the forearm and the lower leg, because we have no means of fixing either the shoulder-joint or the hip. And not only is this principle either impossible or futile, but it is pernicious in the extreme; because it leads, especially in old people, to a stiffness of the fixed joints which causes even more loss of function than that due to the displaced bone.

4. The fourth principle is that the immobilized limb must be surrounded by tight bandages, applied so firmly that they will not allow of shifting during the whole period required for consolidation, whether this be for one, two, or three months. This principle, too, is either futile or dangerous: it is futile if the bandaging be not really firm, and dangerous if it be. The only limb in which it can be adequately carried out is the slender forearm of the child, and then its extreme consequence is 'ischæmic paralysis.' Fortunately, such an extreme consequence is rare; but, nevertheless, a tight constricting bandage left in place for weeks or months can only result in a very severe injury to the circulation.

5. The last principle—or perhaps it ought to be called lack of principle—at any rate, the last feature of the classical treatment—is the total neglect of the welfare of the soft parts and joints of the limb, whilst the bone, lying all awry, is left to mend itself in its bad position. Probably, as regards the ultimate use of the limb, this feature of the immobilization treatment is the worst of all; for the function of the limb in all its finer and more intricate movements is dependent upon the mechanism of movement—the muscles, nerves, joints, and ligaments—much more than upon the passive bone, which is intended merely as a frame upon which the soft tissues work.

This old method, going back to prehistoric times, is almost everything that is bad. It does nothing to reduce the deformity; it allows enough movement between the fragments to cause great callus excess; it keeps the patient in bed, or the limb inactive, for the longest possible time; it does everything to make the muscles waste, the tendons adhere to their sheaths, and the joints to become fixed. And it conceals the prospects of all these evil results beneath the covering of elegant bandages, so that they are not apparent until too late for remedy. One good feature the method has, which with many, unfortunately, outweighs all its evils. At the time, it is easy both for patient and practitioner. Perhaps one half-hour is given to fixing the arm on a splint or to putting the leg into plaster, and then nothing more has to be done for a month or two, except for the patient to enjoy a picturesque convalescence and for the surgeon to chat to him about politics, or the weather, from time to time. Hence it is, that the method which goes back to the Pharaohs seems likely to flourish for many a generation to come, so long in fact as '*laissez-faire*,' '*solvitur ambulando*,' and 'wait and see' are still popular mottoes.

Many who read these words may think them a gross exaggeration and that many a case has done well with splint or plaster treatment. This is quite true, and it is this that makes the whole difficulty. If every case treated by a splint became maimed for life, no argument against the method would be needed. Possibly the majority of the patients treated by it get finally a good result. But this is not because of the treatment, but rather in spite of it: that is to say, immobilization is only treatment in the negative sense of the word—in the same sense that bed is the treatment of enteric fever. Most broken bones, the fragments of which are not much displaced, will heal if protected from further injury. But when much displacement exists, the immobilization will do nothing to restore the proper form to the bone, whilst it will do much to injure the soft parts.

The fixing of a limb on a splint which immobilizes the joints above and below the fracture, and which is not removed for weeks together, ought to be abandoned absolutely, unless under exceptional circumstances—e.g. for patients who are delirious, insane, or quite out of reach of frequent medical supervision. Such treatment is either too much or too little: it is too much for a fracture without displacement, and it is too little for one with it.

It must be clearly understood that the foregoing criticism is directed against prolonged fixation, and not against splints or plaster, both of which have their proper uses. Certain splints, e.g. Hodgen's cradle or Thomas's knee-splint for fractured femur, act well because they are not immobilizing but extending forces. Others, e.g. a Carr's splint for the wrist, or Croft's plaster, serve to aid recovery by providing rest in a proper position; but they must be removed for daily massage and movement after a very few days.

ON THE RELATION OF X RAYS TO FRACTURE TREATMENT.

Inasmuch as skiagraphy has been the most potent agency in demonstrating the false foundations of the old fracture treatment, so it must be made the guide and test of the new. But if such a leading rôle is to be given to the *x* rays, it is of extreme importance that the various reasons why their use is necessary, and the deductions to be drawn from their revelations, should be made clear.

Among many of the laity, it is thought that *x*-ray pictures are a kind of amusement or hobby of surgeons, or a mere gratification of scientific curiosity. And unfortunately this idea is largely assented to by medical men, some of whom even take the attitude that anyone who asks for *x*-ray information is wishing to cast a slur upon the skill of the surgeon. Here, too, the difficulty of proof of the necessity for routine skiagraphy lies in the fact that many do quite well without it. Perhaps in two out of every three cases of fracture no *x*-ray information will be derived which in any way modifies the treatment. But there is no reliable method of knowing which cases do require *x*-ray demonstration except that of taking pictures of all fractures, or suspected fractures, at as early a date as possible.

The prevalent attitude of mind at present among general practitioners is to think that the *x* rays need never be used except in extraordinary cases, and their practice is to allow all ordinary fractures to be put up and kept at rest for a long period, and then, if any obvious disability remains, the case is sent for a skiagram; this usually reveals some unreduced displacement with far-advanced mal-union, and at this period the difficulties of its successful rectification are much greater than if an accurate early diagnosis had been made.

X-ray evidence is necessary in order to avoid overlooking a break altogether in many cases of fissured or impacted fracture; to ascertain the existence of the displacement of a fragment into a position where it may cause injury to the function of a joint; to determine the character of the displacement, and whether it is one, such as that of an oblique or spiral fracture, which is difficult to reduce and liable to late displacement; to decide whether there is so little displacement that the fracture can be treated throughout without the use of splints; and to obtain a record by which the treatment and progress of the case can be determined. And lastly, there is an undoubted legal obligation to use this means of diagnosis. Any fracture case may be made the matter of a legal action, either in relation to workmen's compensation, a claim for damages, or a charge of malpraxis and negligence against the medical man.

It is no answer to these arguments to say that in many cases, for example those of leg fractures in rural districts, the *x* rays are unavailable. It is certainly far better, wherever possible, to have such cases removed to cities where hospitals or nursing homes provide the necessary facilities; but, for the rest, the case must be treated as it would have been before the advent of skiagraphy.

ON THE RELATION BETWEEN FORM AND FUNCTION.

To what extent is the restoration of form in a broken bone an index of the future recovery of perfect function in the limb? Upon the answer to this question depends the whole basis of the modern treatment of fractures.

The data of this problem have been more thoroughly provided by the report of the Fracture Committee of the British Medical Association than by any other source of information with which I am acquainted, and I cannot do better than quote their main facts in this connection. They say (*B. M. J.*, 1912, ii, p. 1525):—

> " An analysis of all the results, non-operative and operative, clearly shows the interdependence of the anatomical and functional result. The total number of cases in which a good anatomical result was obtained is 1736, and in no less than 1576 of these the functional result was also good. In other words: If the anatomical result be good, the functional result is good in 90·7 per cent.
>
> " If the anatomical result be moderate or bad, the functional result is good in 29·7 per cent (i.e. 380 out of 1279).
>
> " If the anatomical result be bad, the functional result is bad in 53·3 per cent (176 out of 330)."

And from these facts they conclude (p. 1505):—

> " Although the functional result may be good with an indifferent anatomical result, the most certain way to obtain a good functional result is to secure a good anatomical result. No method, whether non-operative or operative, which does not definitely promise a good anatomical result, should be accepted as a matter of choice."

This states the matter in so broad and fair a manner that it would be unreasonable not to accept the conclusions; but a little reflection will show that these leave us in doubt about many practical points.

Broadly speaking, then, good form is accompanied by good function and bad form by bad function, and it only remains to consider to what extent these two conditions are cause and effect, and in what light to regard the exceptional cases.

Cases of Good Form with Bad Function.—It will be observed that out of 1736 cases with a good anatomical result there were 160 with a bad functional result, i.e., nearly 10 per cent. And it would be quite easy to write a treatise and give illustrations of these 160 cases, which, taken by themselves, would seem to show that anatomical restoration is of no value at all. Everyone must be familiar with such cases. Three recent instances are at once recalled to my own mind. The first was an old woman with a fracture of the tibia and fibula, which I operated upon by means of intramedullary pegs—with a most ideal result, as shown both by the *x* rays and the rapid union. She left hospital in a few weeks, and more than six months later I wrote for her to come and show herself at a medical meeting, when to my great chagrin she was carried into the room, and told all who asked her that she had never been able to use the leg since the accident!

The second, a lady of 45, had a simple fracture of the olecranon, which I wired, bringing the loose fragment into perfect position with ease and firmness. Healing was primary; no splint was used, but she had massage and movements from the first. Five months later, she was brought to see me again. She had never been able to use her arm because of the pain, which extended from the shoulder to the wrist. Yet the limb was well nourished; there was no anæsthesia or paralysis such as would indicate gross nerve injury, and the *x*-ray picture was quite ideal. I suggested that her doctor, who had been lavishing upon her the most unremitting care, should try treating her with a studied neglect, and that her friends should be tactfully advised to do the same. This plan has been eminently successful.

The third was a working man with an oblique subperiosteal fracture of the fibula in which there was never any displacement. He had massage and movement from the very first; but for months afterwards he refused to attempt to bear his weight on the foot, and it will probably be six months before he returns to work.

These three patients represent very fairly this type of case. In all of them the real trouble is in the will power—whether this be called neurasthenia, malingering, or mere loss of function. The long deferment of recovery is not due to the bone condition, nor to that of the soft parts, but to the mental suggestion, which completely dominates the mind, that the limb has been injured and cannot be used.

There are others in this class where there is definite nerve injury accounting for the loss of muscle power; and lastly, there are those whose tendons have become adherent owing to long-continued immobilization. This last factor is very important in fractures near the joints, especially in Colles's and Pott's fractures.

The deductions to be drawn from this group of cases with good form but bad function are, that although to secure good form is the best way to obtain good function, it will not guarantee it; and that the object of treatment of a fracture is only begun, and by no means ended, when the anatomical structure of the bone is restored. When dealing with neurotic patients presenting only slight deformity, it is probably better from the outset to direct attention to the relief of pain by light massage, and to encourage early movement, rather than to concentrate the patient's mind upon the gravity of the injury by performing an operation.

Cases with Bad Form and Good Function. — In the Fracture Committee's report, there were nearly 30 per cent of cases with moderate or bad anatomical results who, nevertheless, had good function. Here again it would be easy by concentrating attention on these cases to argue that the restoration of the form of the bone does not matter. And one cannot but be startled, when such cases are brought into prominence by the advocates of massage and movements, on noting how wonderful is the range of function sometimes displayed by people whose bones are united in some horrid deformity. But to take such cases and argue from them that the restitution of bone form matters nothing, is to lose sight of the fact that, for every three patients with bone deformity who regain full function, there are seven who never do so. Another point not noted in the above figures is the length of time occupied in recovery of function; if this could be ascertained, it would no doubt show that a large number of those who regain function in spite of a bad anatomical form, do so at the expense of a long period of incapacity.

Cases with Bad Form and Bad Function.—Of all the cases with marked bony deformity, 70 per cent show permanent loss of function. The natural deduction from this is that if the deformity had been corrected these bad results would have been avoided. But, to be quite fair, we must allow for the 10 per cent of cases with good form who, nevertheless, have bad function. We may certainly say then, that by always correcting deformity we should have saved 60 per cent of the cases of loss of function. In other words:—

In 100 cases of good form there are 90 with good function.
In 100 cases of bad form there are 30 with good function.

Therefore, original correction of the bad form in the latter list would probably have led to 60 cases being restored to efficiency.

Advocates of massage and mobility have attempted to belittle the argument about function being dependent upon form, by pointing out that the bad function of a deformed limb often depends upon the long disuse caused by prolonged immobilization. This may be perfectly true for a certain period after the accident, but it will not account for the condition of the limb after the expiration of a year or more. Now, none of the cases dealt with in the Fracture Committee's report were seen less than one year after the accident, and therefore all of them had had at least nine or ten months of movement and exercise.

We may summarize this important part of the subject by saying that the restoration of good form to a broken bone gives a chance of 9 to 1 in favour of a good function; whereas the allowance of a bad form will give a chance of more than 2 to 1 (7 to 3) against a good result.

ON THE KIND OF DEFORMITY WHICH LEADS TO DISUSE.

Up to the present the question of deformity arising from bone displacement has been spoken of in general terms, merely as slight or great. But it is very important to consider the elements of deformity which directly interfere with function; in other words, to inquire what kind of displacement will certainly lead to disuse.

The displacements of which the fragments are capable may be classified simply as follows:—

Displacement in length—
  - Impaction.
  - Overlapping.
  - Gaping—e.g., fractured olecranon.

Lateral displacement—
  - Partial; i.e., fractured ends are still in contact, but there is no overlapping.
  - Complete; with or without overlapping.

Angulation of the long axis of the bone.

Rotation.

A theoretical discussion of the mechanical results of each of these varieties would be out of place in this volume, the aim of which is strictly practical. Speaking from observation and experience, I would say that only two types of uncorrected displacement can safely be said to be followed commonly by good function, viz., impaction without serious alteration of the axis of the fragments, and partial lateral displacement without angulation. All the cases I have seen or read of as instances of good function in spite of bad form, fall under these two types; they are illustrated in the chapter on massage.

Every other kind of displacement will probably lead to more or less loss of function, and therefore should never, in a spirit of careless optimism which trusts to matters righting themselves, be allowed to persist. But here, too, there are degrees of disability to be anticipated. In general terms it may be stated that a displacement is of serious omen in proportion to its proximity to and influence upon a joint. Displacement is more serious in the leg than in the arm, because in the former all its natural functions necessitate bearing the weight of the body, and because the legs, acting as a pair, require parallelism and uniform length.

These points may be emphasized and illustrated by a few cases which have come before my notice recently, chiefly in connection with the Workmen's Compensation Act.

Case 1 is that of a collier who fractured his humerus at the upper end, and was treated by splints and immobilization in the orthodox way.

It will be seen that the shaft of the bone is displaced into the axilla, and that massive callus union has occurred (*Fig.* 1). There are thus three elements of those leading to loss of function in this deformity, viz., shortening, lateral displacement, and the close proximity to an important joint. Permanent total disablement had to be admitted.

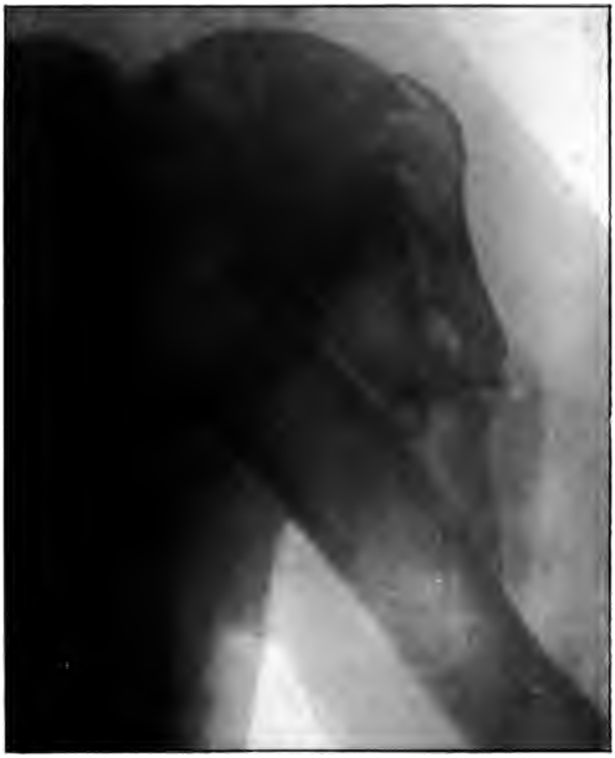

Fig. 1.—Fracture of the upper end of the humerus, with gross mal-union and permanent total incapacity.

Case 2 is a man of 62, who twelve years previously broke his femur. He now has a false joint between the upper and middle thirds of the bone (*Fig.* 2).

Case 3 is that of a labourer who broke his femur in the upper third. It was plated by the ordinary method, and the plating

Fig. 3.—Fracture of the upper end of the shaft of the femur (plated), with marked angulation.

Fig. 2.—Fracture of the upper end of the right femur, with the formation of a false joint.

quickly gave way. The figure (*Fig.* 3) shows simply angulation; but at a subsequent stage, after removal of the plates and screws, he had great shortening, with overlapping in addition. Total disablement.

Case 4 represents a very common condition (*Fig.* 4). It is the femur of a working man of middle age with great overlapping of the fragments. It was treated by that most fatal plan of a Liston's long splint with a trifling weight extension, of which I shall have occasion to speak again later. In this case the man was left a cripple, and the insurance company had to compensate him as permanently disabled.

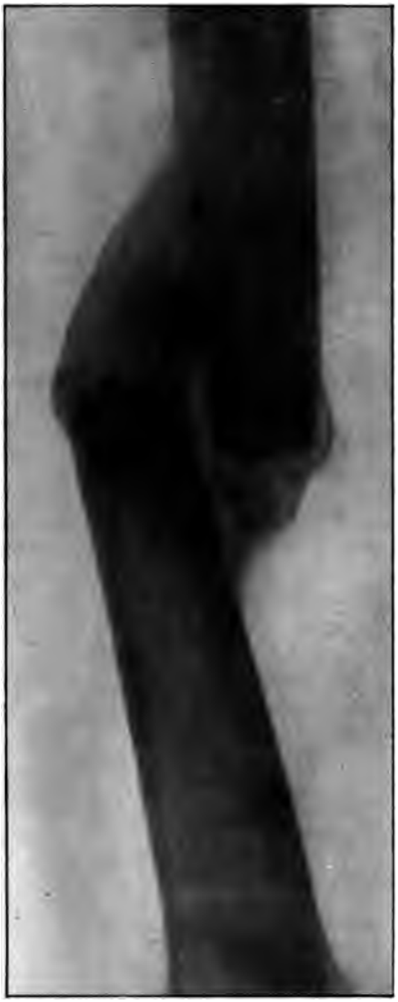

Fig. 4.—Fracture of the shaft of the femur in a labourer which caused permanent total disablement.

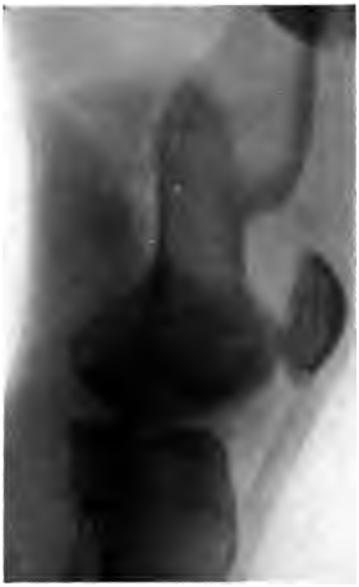

Fig. 5.—Fracture of the lower end of the shaft of the femur, with malunion.

Case 5 was a young man, age 25, with a fracture of the lower end of the femur, treated by immobilization. The skiagram (*Fig.* 5), taken more than a year later, shows that there is the usual backward displacement of the lower fragment, and a mechanical locking of the upper fragment with the edge of the patella. He is now quite lame and unable to work, and this result is partly owing to adhesion of the quadriceps muscle over the site of the fracture.

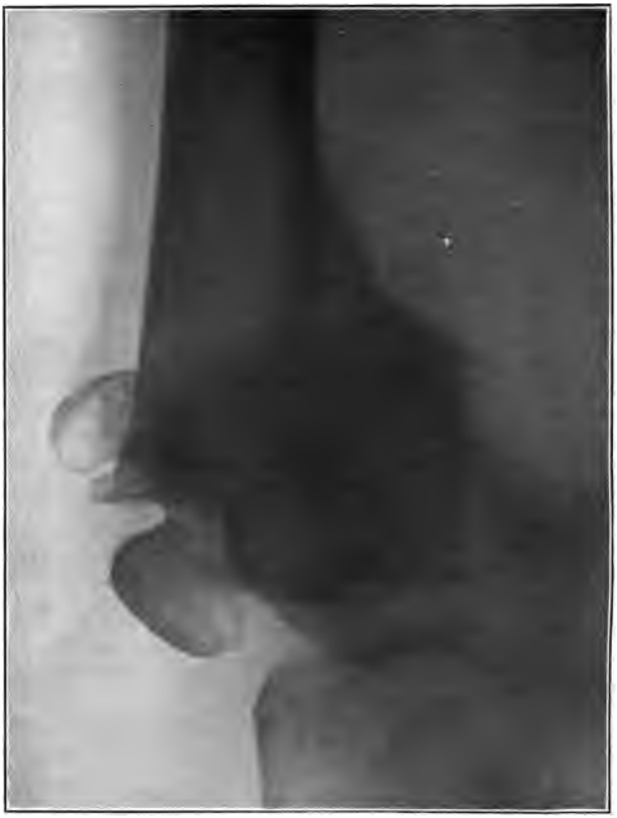

Fig. 6.—Fracture of the lower end of the femur, with backward displacement, associated with fracture of the patella.

Case 6 is that of an old man who had a T-shaped fracture of the lower end of the femur with a break of the patella (*Fig.* 6). The result was a gross disorganization of the knee-joint, with almost complete loss of movement. This patient was to have been the subject of litigation in the county court, but the insurance company, on seeing the skiagram, preferred to pay him on the basis of total permanent disablement.

Case 7 is that of a lady who broke both bones of her leg fourteen years before the date of the skiagram (*Fig.* 7), and who was treated by the usual 'three' splints left in position for seven weeks, followed by six weeks in plaster. Whatever the original displacement, the element remaining is angulation, which so throws the line of the knee- and ankle-joints out of gear that she has a chronic synovitis with effusion in the knee-joint, with laxity of the internal lateral ligament, and a painful flat-foot in which there is already evidence of osteo-arthritis. This case is very important, because there is no shortening of the leg, and this test is generally relied upon as proving that the position is correct; and also because it shows that the disability

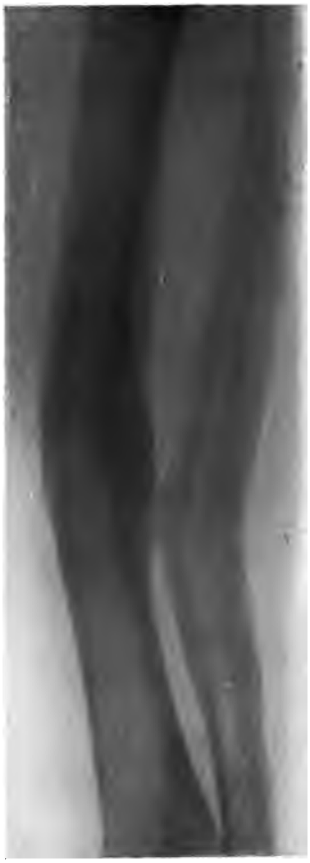

Fig. 7.—Old fracture of leg bones with angular deformity, which caused secondary changes in the knee and ankle.

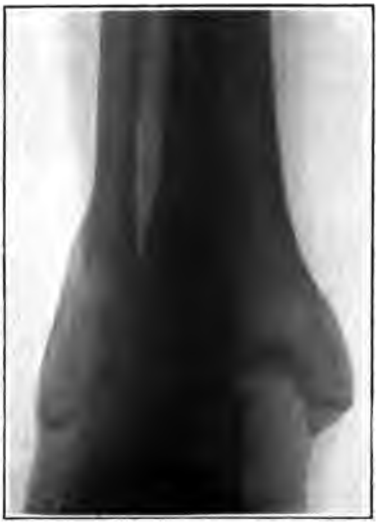

Fig. 8.—Pott's fracture, with permanent widening of the socket of the ankle-joint.

accompanying displacement often increases with the lapse of time. In the leg in particular, a bent bone often becomes more bent, and the joints develop osteo-arthritis.

Case 8.—The last case is that of a carter who sustained a malleolar fracture which was treated by a rather unsatisfactory kind of massage and mobilization; that is to say, he had to depend upon rubbing and exercises administered by his own friends. It will be seen (*Fig.* 8) that though firm union of the external malleolus has occurred, there is marked lateral deviation, which leaves the joint socket for the astragalus about half as wide again as it ought to be; thus, when he walks, the foot twists out, and he has a painful and weak type of talipes valgus which is never likely to improve unless the bone deformity can be put right.

ON THE RELATION OF AGE, OCCUPATION, AND LAPSE OF TIME TO THE IMPORTANCE OF BONE DEFORMITY.

There are certain factors of very great importance, apart from the extent and character of the displacement, which have an important bearing on after-function. The age of the patient is perhaps the chief of these. In childhood and during the period of active bone growth, the majority of traumatic bone deformities will be lessened or fully corrected by the moulding hand of time. Particularly is this the case in lateral displacement, in which the adjacent sides of the overlapping fragments fuse and are absorbed, and ultimately a new bone is constructed which is quite perfect. To some extent the same process occurs in adults, but with nothing like the same rapidity or in the same perfection. This capacity for restitution of form of a slightly deformed bone in children, together with the comparative facility with which gross displacements can be reduced, accounts for the excellent prognosis after these accidents. I can call to mind at the moment only two conditions of deformity in children, resulting from fractures, which caused so much loss of function as to necessitate operation. The one was simultaneous fracture of both bones of the forearm, and the other, fracture of the lower end of the humerus.

Apart from this question of age, we must inquire, too, what effect the lapse of time will have upon deformities, especially in the case of adults. This is difficult to answer concisely, for there are some deformities which certainly become less, by the mere rounding off of projecting angles and the filling up of curves; and often the loss of function becomes much less with the lapse of time, by the various muscles readjusting themselves to their new relations. But, as in *Case* 7 related above, time does not always cause a betterment, but rather an increase of disability, in the conditions which are associated with bone deformity. This comes about in various ways. It is seen particularly in fractures which cause deformity of joints, and in those which have to bear a great strain tending to increase the deformity; the repaired bone may undergo a slow process of bending, or even of further overlapping of fragments, for months or years after the accident; or there may be developed in the joints a process of abnormal growth which hinders movement, either osteo-arthritis or mere callus excrescences.

The factor of occupation is so obvious as hardly to require more than mention. This is well illustrated by the case of a violinist with fracture of both left forearm bones. The lower ulnar fragment was displaced inwards, and he could not supinate the hand. He could do all ordinary movements, but he could not hold his violin. If we distinguish between two elements in labour, viz., strain and skill, there can be no doubt that deformity is much more serious in relation to the latter than to the former.

THE NATURE OF THE MODERN PROBLEM.

The problem of the treatment of fractures consists in the rapid restoration of the injured limb to certain and complete function. To this end three things are necessary: (1) The will of the patient; (2) A sufficiently perfect restoration of the form of the bone to allow of perfect joint action; and (3) The preservation of the full vitality of the circulation and neuro muscular apparatus.

The first of these is a factor over which we have very little direct control, and a lack of this must always cause a certain proportion of failures by any method. But, apart from malingering, the failure of will-power in neurotic patients is brought about much more by elaborate and complicated treatment, and especially by operation, than by that which is simple and suggestive, from the very outset, of the power of movement and activity.

Of the other two more material factors, which may be referred to briefly as 'bone' and 'muscle,' there can be no doubt that the 'muscle' depends so much upon the 'bone,' that it is our first duty to secure accurate anatomical form, and our second to maintain proper and healthy muscular nutrition and exercise. By putting the muscle first there is great danger of the bone being permanently deformed, whereas by considering the bone first, even if the muscle is for a time neglected, the final result promises to be good; for muscular condition can be restored when the bone is satisfactory; whereas the bone deformity, with its resulting effect on the joints, is permanent, and will cause disability, however perfect may be the muscle conditions.

Thus, the solution of the problem is to be made in the following stages:—

1. Diagnosis and observation of the exact nature of the fracture from the outset, and at frequent intervals during the course of treatment, by means of the *x* rays.
2. Restoration of the bone deformity so that nothing but partial lateral displacement or impaction, without alteration of the axis of the limb, is allowed.
3. The retention of this restored position so that displacement does not occur during healing.
4. Preservation of the vigour of the muscles and circulation from the outset by early movements.
5. Early restitution of functional utility by properly graduated exercises.

MODERN METHODS OF SOLVING THE PROBLEM.

Now, whereas these principles would, I believe, be subscribed to by most modern authorities on fractures, those who have been active in the matter have each tended to exalt one particular factor over all the rest, and hence there have arisen the different modern 'methods,' which appear at first sight to be opposed to one another, and which undoubtedly have greatly weakened their position with the profession at large by competing against, instead of co-operating with, one another.

The general practitioner is not going to give up his cherished belief in the old system, in which at one time everyone believed, for the sake of a new system against which its contemporary rivals provide him with arguments of derision.

But there is in reality no opposition between the principles of the various new methods. They can all of them be included under the above scheme for the solution of the fracture problem. The apparent antagonism has arisen from an attempt to exalt each method into a universal and self-contained system, independent of other methods: such an attempt being often quite contrary to the expressed or implied view of the original authors of each.

These new methods may be grouped under three main divisions and several sub-divisions. Thus :—

I. *Methods of Massage and Mobilization.*

When these are proposed as the sole or chief methods, it ought to be implied either that serious bone deformity does not exist, or that it can be reduced and retained in proper position by manipulation under massage or anæsthesia or by operation.

II. *Extension Methods.*

a. By means of adhesive plaster and weights or springs with the limb in a position of extension, the joints being left quite free from fixation.

b. Extension applied to the limb with the joints in a position of semiflexion.

c. Extension by means of transfixing rods or nails.

III. *Operation Methods.*

These methods involve the exposure of the seat of fracture, the direct reduction of the deformity, and fixation by wire, plates, screws, pegs, or grafts.

Each of these three systems solves the problem in a different way, or rather they attain the solution by different routes.

Massage acts by abolishing muscular spasm, and in this way early movement is possible without displacing the fragments. It can only be supplementary to other methods if gross deformity exists.

Extension acts by a direct counteraction of the muscular contraction, steadily maintained until union is firm ; but maintained in such a fashion that the joints can be moved and the muscles massaged during the treatment.

Operation directly exposes the seat of the fracture, and fixes the broken bone so that displacement cannot recur. After this has been done and the wound has healed, movements of the joints and early use of the limb should be undertaken.

It will be clear from this account that each method will have its own special rôle to perform. Gross deformity is to be corrected and fixed by operation, especially in the leg-bones and in adults, and in all cases where one week's extension and massage has failed to procure reduction. Extension is to be applied for the same purpose in cases where operation is refused or is unsuitable, and in those cases, especially in the arm-bones and in children, where it readily succeeds. And early movement, made possible by light massage, is for the early restoration of muscular function in all cases, being the sole treatment in those cases only where there is no serious displacement.

ON THE NEED FOR CO-OPERATION BETWEEN THE DIFFERENT SYSTEMS.

Each of these systems is founded upon some definite principle of truth. That of mobilization, on the principle of the dependence of function upon the healthy condition of the soft parts; that of extension, upon the principle of abolishing displacement by counteracting the displacing force; and that of operation, upon the principle of the necessity for perfect anatomical restoration in order to secure the surest prospect of full functional restoration.

Every one of these principles is true, and in no way contradictory of the others; and this being the case, it follows that no one can be in a position to do justice to the whole subject unless he has mastered each principle, and knows when to select one, when to turn from one to another, or when to seek the co-operation of more than one at the same time.

If, for example, the advocate of mobilization be not conversant with the results of operation, he will be liable to push his method too far, and run the risk of leaving gross bone deformity. Or if the operator has no personal experience of the brilliant results which follow mobilization in cases of slight deformity, he will perform unnecessary operations. And again, if it be really true that early mobilization is the essential condition for rapid restoration of function, this does not cease to be the truth if the case be submitted to operation; and the latter ought to be performed in such a manner as to allow of mobilization at the earliest possible moment.

CHAPTER II

MASSAGE AND MOBILIZATION

THIS system deserves to come first among modern methods of fracture treatment not only because of its simplicity, but also because of its wide applicability, and because in its fundamental principles it ought to find a place in conjunction with other methods in every fracture case without exception.

First, however, it is necessary to refer to the great misconception of the 'massage' treatment which has always existed among English surgeons, as evidenced both by their practice and by the teaching of current text-books. This misconception is no doubt due largely to the unfortunate fact that the name by which the system is known is used in two quite different senses. Massage as ordinarily practised, with all its manifold pressures and kneadings, is well known to every practitioner and nurse, and to a good many of the public. 'Massage' as advocated by Lucas-Championnière and his pupils is something entirely different; and I venture to think that his method would have been more widely understood and more accurately practised if he could have found for it a simple and distinctive title. The late Professor did invent the word 'gluco-kinesis' to designate the essential feature of his treatment ; but such a name is too cumbrous for common use. If we were bold enough we ought, really to call this method 'The treatment by hypnotism'; then we should have no doubt that it was a subtle appeal to the nervous system rather than a gross one to physical force. It is beside the point altogether to say that this light massage is not hypnotism. If it is not hypnotic, we may well ask its authors how to distinguish it from hypnotism. Every advocate of the method, as a matter of fact, is most emphatic that it is not massage in the ordinary sense of the term, and yet he continues to call it massage—with the result that he often gets served with the wrong goods—rather than call it hypnotism and thereby get what he wants, at the cost perhaps of some sneers.

As too often applied, the massage treatment of fractures consists in first splinting a fracture for days or weeks until early union has occurred, thereby producing stiffness of muscles and joints; then a professional masseur is called in to give a daily rubbing. The limb is punched and pummelled, and the joints moved with more or less force: and the more pain caused, the greater good is the massage thought to be doing. It may well be doubted whether such treatment advances the progress of recovery by a single day; in fact it often positively retards it.

As it ought to be practised, the method consists in applying a gentle superficial stroking, a soothing caress, to the injured part at the very outset, even preliminary to diagnosis. The criterion of efficiency and the promise of success must always be the relief and not the causation of pain. After the part has been lulled to sleep by this light stroking, the spasm of the muscles relaxes and the displacement can be reduced. The limb is then protected from injury by a bandage or splint, and this treatment is continued daily until all retentive apparatus can be discontinued. From the outset, all the joints in the limb are moved, after pain has been abolished, and in such a way as to cause no new pain.

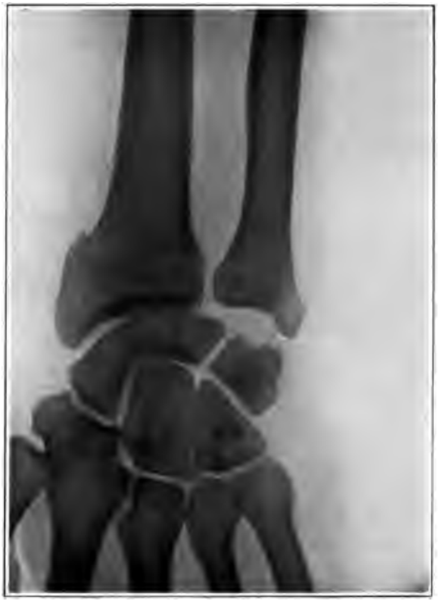

Fig. 9.—The right wrist of an adult with a Colles's fracture. The patient was a surgeon, and he was able to operate within fourteen days of the accident. (*Mennell.*)

There are three quite distinct groups of cases in which this method may form the only treatment, though the proportion of good results obtained by it in each is probably very different.

First, there is a group in which there is no displacement of the bone fragments, nor any great tendency to displacement, as, for example, many fractures of the lower end of the radius or of the shaft of the fibula. In such cases, there can be no doubt as to the absolute efficacy of the method and its vast superiority over all others. A patient with a Colles's fracture will have full use of his hand at a period when by the old treatment he would have just been released from his splint, with stiff, painful, and useless joints (*Fig.* 9).

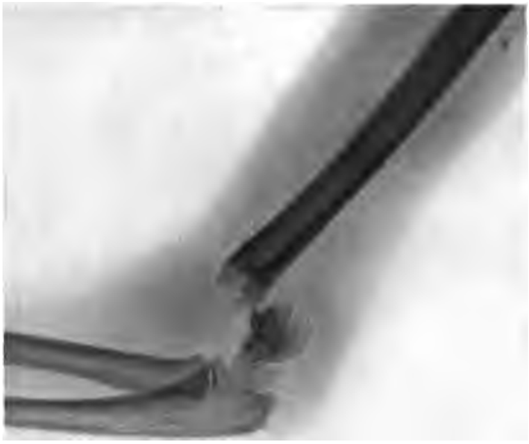

Fig. 10. –Fracture of humerus, at date of accident.

This and the three following figures are from a girl of 11, treated by massage and movements. They show complete restoration of both form and function. (*Pirie Watson.*)

Secondly, there is the group of cases where gross displacement exists, but where such displacement can be reduced under the soothing influence of stroking, with or without the addition (not substitution) of general anæsthesia. Inasmuch as displacement of the bone fragments in a fracture is due largely to the pull of muscular spasm, there is no reason why in some cases such displacement should not be easily reducible, or even should reduce itself, if and when the muscle spasm is abolished. If the treatment has been efficient, this reduction of displacement should have occurred within the first few days, and can be verified by means of the *x* rays. If it has failed and the displacement remains, nothing has been done to prejudice the success of further treatment by extension or operation. Probably the most successful cases in this group are to be found in fractures of the upper and lower end of the humerus (*Figs.* 10, 11, 12, 13).

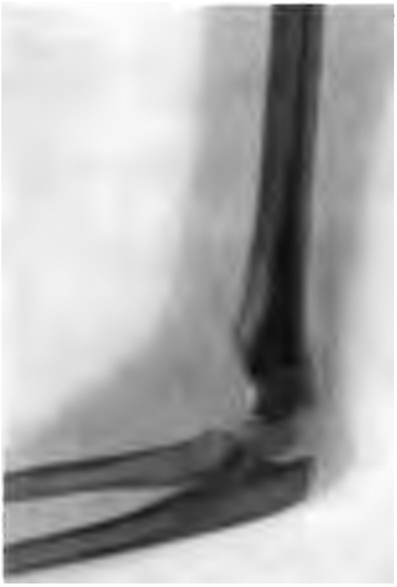

Fig. 11.—Nine months after accident, showing good alinement of fragments.

Thirdly, there is a group where displacement occurs which either cannot be reduced by the treatment or which recurs in spite of treatment. In such cases, where the patient is young and the conditions in other respects are favourable, extension or operation should be adopted. And again it may be noted, that a week of treatment by 'massage' not only does nothing to make the case less favourable for operation, but makes for more assured success, by maintaining the vigour of the circulation,

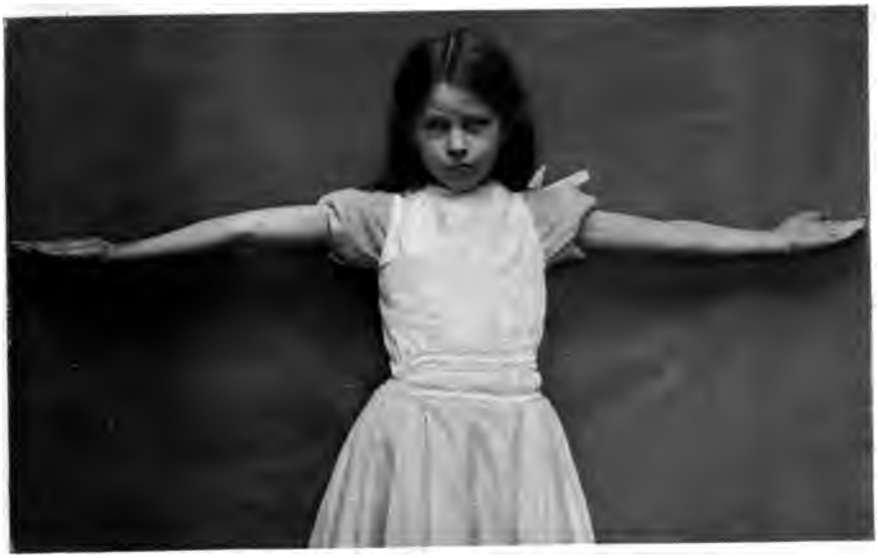

Fig. 12.—Slight hyperextension at right elbow.

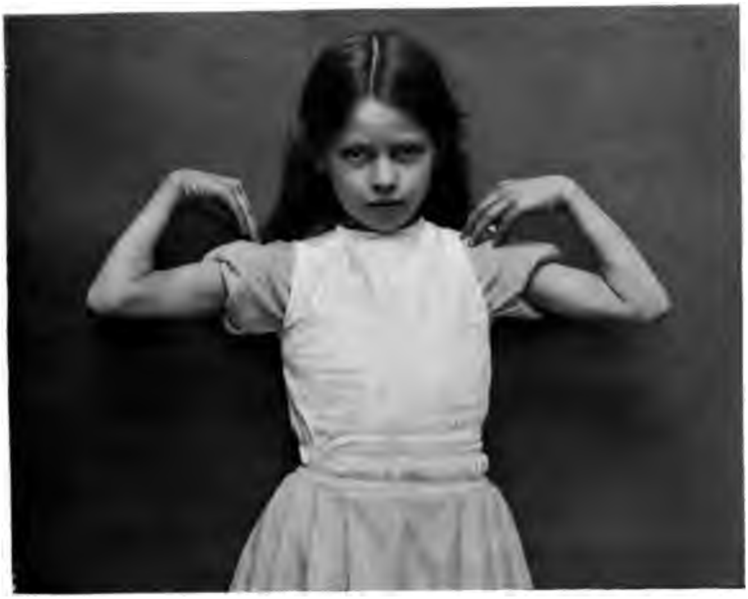

Fig. 13.—Slight diminution of flexion at right elbow.

hastening the absorption of exudates, and diminishing muscle spasm. But there are many cases in this group in which operation is contra-indicated, either by the age or refusal of the patient, an unhealthy condition of the skin, or some other difficulty. In some of these a judicious combination of massage and extension methods will give good results, and in some of them, massage alone will give perfect functional success in spite of the persistence of anatomical deformity (*Figs.* 14, 15). This is another matter in which the massage method has been misunderstood and unfairly condemned. It is often assumed that it ignores the question of deformity altogether and sets up the principle that recovery of function is independent of recovery of form. This is quite incorrect. In all cases gross deformity must be reduced if possible, but if such reduction is impossible and operation cannot be undertaken, then the method of massage will give a far better and speedier prospect of recovery than mere immobilization.

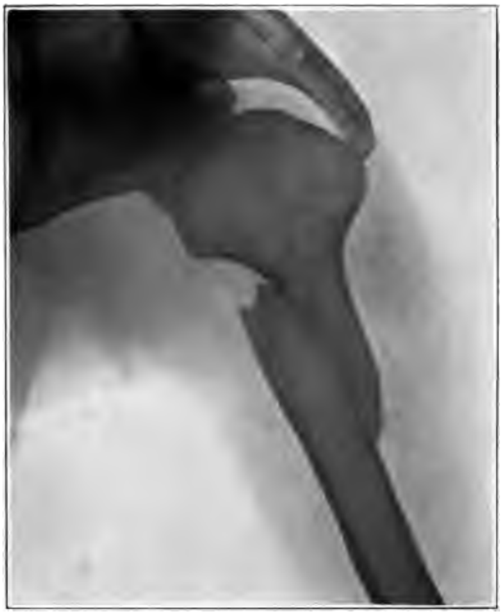

Fig. 14.—Oblique fracture below surgical neck of the humerus in an old woman. Good functional recovery under massage and movements. (*Pirie Watson.*)

The term 'gross deformity' will always be open to some variety of meaning, and be the subject of much difference of opinion. Lateral displacement of the fragments without shortening and without alteration of the axis of the bone has but little effect on function. Alteration in the axis of a limb, especially the lower limb, is more important than mere shortening, and any displacement of fragments near a joint will be much more serious than one affecting the shafts of the bones.

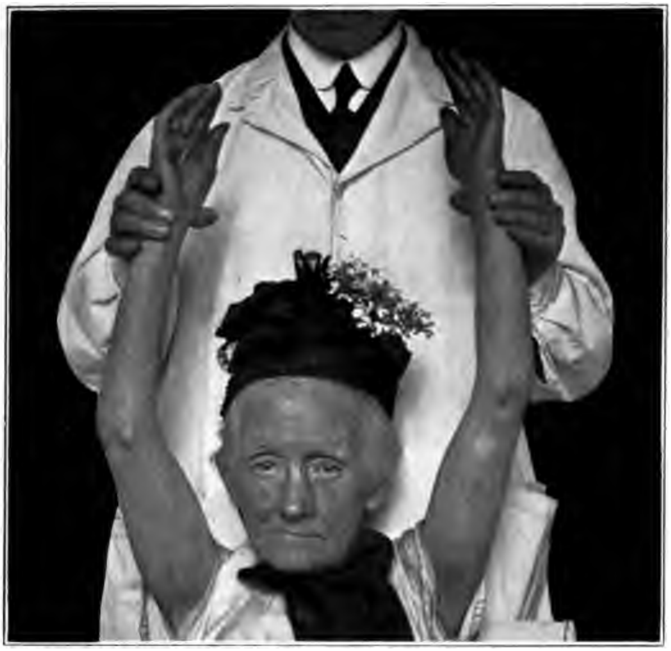

Fig. 15.—The patient from whom *Fig.* 14 was taken. One year after the fracture, showing the range of movement possible. (*Pirie Watson.*)

Impaction of a fracture without marked alteration in the axis of the limb is to be regarded as a good thing, and on no account to be broken down for the sake of obtaining a more correct anatomical position. For example, a Colles's fracture with slight abduction of the hand is to be left as it is ; but an impacted fracture at the neck of the femur producing a position of coxa vara is to be disimpacted.

But in addition to those cases where other treatment is not needed or cannot be applied, there is all that great group of cases which have been treated by either extension or operation for the reduction and retention of the deformity, and in which the addition of massage will make all the difference between a smooth, painless, and complete recovery of function and one that is slow, troublesome, and only partial.

If the cardinal principle of massage is the soothing of pain and the relief of muscle spasm, then not only ought it to be applied as much to cases after as before operation ; but if the operation has been done properly, the massage and movements can be applied afterwards with never a fear of displacement.

To operate upon a broken limb and then tie it up to a splint for a long period, is like mending a broken piece of machinery and then allowing it to rust. Eventually the rust can be cleaned and the parts oiled—but such a rusting process can only be to the permanent detriment of the mechanism.

Having thus indicated the general scope of this method of treating fractures, it will be well to consider its nature and its method of application in greater detail.

Let us take a case of Colles's fracture of the usual variety, with impaction and slight deformity. The patient is seen within an hour or so of the accident, and is in great pain. Preliminary examination is of the simplest description, hardly more than the inspection of the swollen part and a listening to an account of the accident. For the moment it does not matter if the case is one of sprain, separated epiphysis, or fracture. The patient is to be seated opposite the surgeon, and the hand gently taken in his. Then, the sleeve of the patient's coat or dress having been removed, with the other hand the arm is gently stroked by a light caressing movement, from the hand to the elbow, with slow and monotonous regularity, at the rate of about twenty passes per minute. Within five or ten minutes this has had the effect of allaying the patient's alarm and soothing his pain, and the part can be examined more freely. The existence and locality of a fracture is confirmed by the discovery of a spot of great tenderness just over the broken bone. The light massage is then continued, but as soon as a condition of numbed sensation has been induced, gentle rhythmic movements of the wrist and hand are carried out passively whilst the stroking is still going on. It is not necessary to turn the arm about so that each surface can be rubbed, because the nature of the process is nervous and not physical. But often, by changing hands, the back of the arm can be dealt with alternately with the front, to the advantage both of patient and operator. The whole of the first séance lasts for about twenty minutes, at the end of which, if the treatment has been successful, the patient ought to be perfectly comfortable. The arm is then lightly bandaged to a splint—of which Carr's is certainly the most comfortable—and placed in a sling.

Having arrived at this stage, arrangements should be made to have an *x*-ray picture taken, so that the matter of diagnosis shall be settled definitely. About this question there has been expressed much difference of opinion, and many have deprecated the use of *x* rays in any case when the course of treatment was clear. Others seem to suggest that a recourse to skiagraphy is a confession of inability in diagnosis, and it is common for modern text-books to insist upon the necessity of all manner of difficult and often painful manœuvres in order to make certain of diagnosis, and then to admit that it may be well to confirm this by the *x* rays, as though the dependence upon the latter displayed a want of knowledge and skill. Others quite admit the necessity for routine examination of injured limbs by the *x* rays, but insist that the patient should not be allowed to see the skiagram. It is now universally recognized in the law courts and by the lay mind that an *x*-ray record should form a part of the routine treatment of every bone injury, and in the face of this it would be folly to do otherwise than act on this view, which after all is the common-sense one. If we can see what is the matter with the bone we ought to do so, and if we are going to do this, why submit the patient to a long and painful manipulation in order to acquire uncertain information that can be gained certainly by proper radiography without any discomfort to the patient ?

As to the patient seeing the picture, I would suggest that it is worse than useless to try and prevent this in the case of any person who is wishful to do so. If the case progresses well, the patient is apt to wonder whether a bone has really been broken, and a skiagram will prove beneficial in making him obey instructions. If it progresses badly and the patient is dissatisfied, it is folly to try and keep the skiagram hidden from him. Any attempt to do so would arouse his suspicions, he will take an early opportunity of having an *x*-ray picture taken by a photographer, and this will be discussed by the patient and his friends, with the possible addition of some person, either lawyer or doctor, hostile to the original surgeon.

In matters of important detail too, the *x* rays give more reliable information than any other method of diagnosis. This is especially true of fractures into joints. A piece of bone may be displaced into the joint cavity, the presence of which may give no immediate sign, but be capable of completely spoiling the final functional result. A fracture of the spine of the tibia is a good example of such an injury, and the overlooking of this may lead to endless trouble both to patient and practitioner.

Therefore, let it be laid down as an axiom that an *x*-ray picture of the injured part should be taken in two different planes in every case of suspected fracture, as soon as possible after the accident. In bad cases with displacement, this should be repeated after treatment for reduction has been undertaken. And if the patient shows the slightest disposition to see the picture himself, by all means show it to him and explain its significance.

The treatment thus begun is continued on the same lines daily. Every day the splint is removed and the limb is stroked for five minutes, then all the joints are gently moved for just that amplitude which causes no pain, the massage being continued all the time when practicable, and being administered without movements for the first and last five out of the whole twenty minutes. After a period of from four to seven days the splint is discontinued, and in the second week active movements of the fingers, wrist, elbow, and shoulder are ordered, but only such as require no strain and cause no pain. In the third week the exercises are continued, and such movements advised as the use of knife and fork and the buttoning of clothes. During the whole three weeks, the daily massage is to be continued, and supplemented after the first few days by local massage over such areas as that of the internal lateral ligament, where local pain is likely to persist.

The patient should be able to return to light work, e.g., that of a dressmaker or clerk, within four weeks, and to heavy manual labour within eight weeks of the accident.

Take now a case with much displacement of the fragment. In the first place it is wise to be guided in one's estimate of displacement by the *x* rays rather than by examination of the hand. The classical dinner-fork deformity is due largely to the fact that there is much swelling of the tendon sheaths on both sides of the wrist. This is more apparent below the posterior annular ligament and above the anterior, thus exaggerating the bony deformity. Serious displacement will be shown more by an alteration of the line of the wrist-joint than anything else. The articular surface of the radius may look backwards towards the radial side, and such displacement will surely lead to functional injury of the joint. If the lower fragment is loose it may be replaced, and this usually can be accomplished if the case is seen within a few hours of the accident; but after twenty-four hours or more it is very difficult indeed.

The replacement of the fragment, and indeed the discovery that there is a loose fragment, in this and all other cases, should be made only after the limb has been soothed and pain abolished, if possible, by the preliminary massage. If this has been highly successful, it may be possible in the hands of an expert to carry out the reduction with no other anæsthesia than that induced by the stroking. But for most practitioners, with whom the present author would include himself, it is seldom possible to accomplish this sleight-of-hand, and recourse must be had to full general anæsthesia. If, however, this is done, there is a great advantage in giving a full dose of light massage with gentle finger movements after reduction and whilst the patient is recovering consciousness, i.e., for a period of about fifteen minutes; this does much to abolish pain and lessen the chances of recurrence of deformity by muscle spasm. Afterwards the limb is put up on a splint and the further treatment is continued exactly as in the case already described, except that possibly the length of time during which the splint is worn may be lengthened somewhat. As a matter of fact, when once reduced there is not much tendency to fresh displacement in a Colles's fracture, and the use of the splint is rather a question of the patient's comfort and security from further injury than a necessity for holding the bones in place. In a bad case and with a nervous patient, the massage and finger movements can be carried out for the first few days without removal of the anterior splint; but nothing justifies an encircling bandage being left untouched for even a few days.

I have described the treatment of a case of Colles's fracture, because this is the type in which the treatment is most easily carried out, and in which it has no rival in other modern methods. It may be well now to consider special points in this method which call for further description or elucidation.

At the outset must be asked the question, *Who ought to undertake the treatment?* Should it be the surgeon himself, a masseur, nurse, or an uninstructed relative? To obtain the best results undoubtedly the case should be seen by the surgeon himself within a few hours of the accident, and treated by him daily for the first seven to twenty days; after this, the patient himself, with the assistance of a nurse or relative, must conduct the exercises, which at that period constitute the most important part of the treatment. But this ideal can seldom be carried out, and this fact accounts more than anything else for the limited use of this method. Enthusiasts like Prof. Lucas-Championnière in Paris and Dr. Mennell in London set up clinics where they have themselves carried out the method with a brilliance of result that ought to have perpetuated the system in those places. And yet one may inquire in vain to-day in Paris and in London for any public institute where the 'massage' treatment of fracture is regularly practised.

But the facts that it seems impossible to establish places where the method can be carried out wholesale, and that it cannot always be conducted by an expert, are no reasons why it should not be pursued as far as possible. In actual practice, the surgeon will only see the case for a short time and at intervals of every few days, and it is seldom that he can pledge himself to give the allotted half-hour daily with any regularity. What then is to be done? Everyone agrees that it is most dangerous to apply to an ordinary professional masseur. Quite foreign to his ideas of massage is the light caressing stroke which is needed, and he will, with the best will in the world, rub and pinch, twist and pummel, the patient in a way which not only does no good, but inflicts positive injury. Either a specially trained nurse must be employed or some intelligent non-professional friend. The latter can readily be instructed, and can, after the first two or three days, be trusted to carry out the stroking and movements without causing pain. Under these circumstances it is wise only to treat cases without displacement, and then the result, though not so rapid as when the patient is throughout under experienced hands, will in the long run be quite satisfactory. I believe that in such cases it is as much the negative as the positive elements in the treatment that do good. For example, in a subperiosteal fracture of one of the leg-bones, it is the absence of splints and the fact that the toes, ankle, and knee will be moved by the patient, whether he be told to do so or not, that account for his speedy recovery, however clumsily the rubbing is done.

The general nature of the massage has already been indicated. It is a light and caressing stroke carried out with monotonous regularity in the long axis of the limb towards the trunk, and the chief criterion of its success is the relief of pain. It ought not to be difficult for medical men, with their knowledge of physiology, to understand the rationale of this process. The effect of a light stroke over the skin of the groin is seen to be a contraction of the cremaster muscle, and this is caused by a reflex action dependent upon the health and integrity of the nervous system. It is quite certain that every sensory nerve when stimulated must convey a certain impulse to the central nerve ganglia, and that from this there must proceed definite peripheral effects. If these be motor to superficial muscles, their result can be seen, but if they happen to be inhibitory or merely vasomotor, then they will be demonstrated by less obvious evidence. And this evidence of the result of light massage is given by the relief of pain, the inhibition of muscle spasm, and the rapid disappearance of œdema.

It is important to insist upon the nervous nature of this process, in order to dispel the fatal misconception that the treatment is a purely local one, the action of which depends upon physical force. This misconception leads to the idea that œdema must be squeezed out by deep pressure, that joints must be moved by force, and that pain must be endured as a part of the necessary accompaniment of the treatment.

All the symptoms of a fracture (as apart from objective signs) are dependent upon the nervous system, to a large extent. Pain is caused by an irritation of sensory nerves and by muscle spasm, œdema is due to vasomotor paralysis much more than to local injury of vessels. Loss of function is due to nervous inhibition of movement. The most striking evidence of the truth of these statements is found in the wide distribution and rapid occurrence of œdema, pain, and loss of function associated with a small local bone injury. With an impacted fracture of the base of the first metacarpal bone may be associated an arm swollen, painful, and useless as far as the elbow—and these conditions are all well marked within a few hours of the accident. If, then, all these symptoms of the fracture are called forth by the nerve reaction to the injury, is it not reasonable to expect them to yield most readily to an efficient system of nerve therapeutics?

The soothing of pain, however desirable a feature of the treatment, is merely a means to an end, and that end is the relaxation of spasm and the making possible of movement. The great dictum of Lucas-Championnière was that " movement is life," and this is the ideal to be kept before us in every system of fracture treatment. The primary function of the limb is movement, and the longer that function is held in abeyance the slower will be its full restoration. Why do joints become stiff in association with fractures ? The commonly given answer to this is — adhesions. Yet it is perfectly easy to prove that in the majority of cases this is quite incorrect. A man has a fracture of the femur, and after a few days of any ordinary treatment, whether by splint, extension, or operation, the knee will be found to be almost rigid. This cannot be a question of adhesions in the joint, because the rigidity disappears at once under an anæsthetic. It is the result of muscle spasm, and can be abolished only by soothing and dulling the nervous mechanism concerned.

No doubt if the rigid joint be kept immobilized for a long time there will be an organization of the exudate in the tendon sheaths, and thus adhesions of this sort may be a late result; but they are certainly not the cause of painful rigid joints in the first instance.

Therefore, movement is to be the great object aimed at by this system of treatment, and this movement, to be curative, must be both early and painless. It must be applied to every joint of the affected limb, to the fingers and wrist of a fractured shoulder, and to the hip and knee of a broken ankle. At first, the object of the movement is simply to aid in the restoration of the stagnant circulation ; in this connection it has been well termed 'internal massage.' For this purpose it is evident that the movements need not have any great range, and they never ought to have such a range as will cause the pain which indicates that the nerve mechanism is being insulted instead of soothed.

The time at which active movements may be commenced, depends chiefly upon the liability of the fracture to displacement. In an impacted Colles's fracture they should be begun within the first few days, as early in fact as they can be undertaken without pain, and if possible only after the massage séance.

If the fracture has been through the shaft of the bone and is oblique, then active movements must be postponed until consolidation has taken place. This is readily determined by the feeling imparted to the hand of the surgeon, and takes usually about twelve to fourteen days. The variety and scope of the active movements should be the same as that of the passive, and amplitude of range and resistance gradually increased, as the patient can bear it.

Before discussing the scope of this method as the principal agent in the treatment of fractures, it may be as well to consider the results given by it in various groups of cases, as compared with the figures furnished by the Fracture Committee's report for the various non-operative methods in English hospitals, which were chiefly methods of splint immobilization. The massage figures are taken from Mennell's book, derived from the 400 cases treated by himself. As Mennell's clinic was concerned with out-patients only, it must be remembered that many of the more severe or difficult types of fracture are not represented in his lists; but, on the other hand, as the groups in which this comparison is made are only cases of arm fracture, and as these are almost all treated as out-patients in English hospitals, the comparison cannot be regarded as an unfair one.

Description of Fracture	Incapacity		Total Disablement	
	Fracture Committee Report	Mennell	F. C. R.	M.
Colles's	Average = 17 weeks	50 % = 4 weeks 95 % = 8 weeks	14 %	0
Neck of Humerus	Average = 27 weeks	Average = 7 weeks Longest = 11 weeks	10 %	0

There now remains the most important and difficult task of considering in what cases this method should be relied upon as the chief agent of fracture treatment. For it is quite clear that the general principles above described ought to be applied to every case of fracture as far as is practicable. Whether the bone be united by operation or the fragments kept in alinement by extension, the function of the limb must be preserved by early movement, and this can only be done without pain or injury after massage has been administered.

But in which cases is massage with movements alone sufficient to give a good result without any other mechanical aid? This question will, of course, be answered differently by various persons, according to their knowledge and experience of the method. The expert in massage treatment believes that every type of fracture is amenable, and would seek other means in cases only where serious displacement persists after several days of stroking have proved fruitless. But unfortunately there are very few experts in this art, and therefore it is more important to decide what are the limitations of the method in the hands of an ordinary surgeon who is prepared to give some time and trouble to the matter both in its study and practice.

Incomplete and subperiosteal fractures may be mentioned first, because about these there can be hardly any difference of opinion as to the benefit of the treatment by mobilization. The *x* rays here are invaluable in giving confidence to the most inexperienced to venture upon the treatment, because by their aid it can be seen that no displacement exists, and there is no excuse for any splinting or immobilization of the joints. In such cases there is no fear of dislocation, deformity, or callus excess; but there is much danger of œdema, with stiff, painful, and useless joints. Bandaging such a limb on a splint is not only useless, but it is the very treatment which is calculated to make all these symptoms worse.

In the massage of such cases two errors must be avoided. On the one hand it may be thought that the case is so trivial that ordinary rubbing will serve quite as well as the 'light caress,' and hence the patient will be in pain all the time during the first week or two, and will perhaps be slower in his recovery than one who, with a complete fracture, had had efficient massage. On the other hand, it may be thought that as there is no displacement and only partial loss of continuity, the fracture can be ignored and muscular effort not restricted. This again is a mistake which causes pain, delay, and disappointment.

Take, for an example of these fractures, a fissured fracture of the head of the radius. I venture to think that a person with such an injury nowadays runs a much greater risk of being inadequately treated than if he had a bad break through the shaft of the bone. Either the nature of the injury is overlooked, or else, having been discovered, it is 'rubbed with liniment,' and the patient is encouraged to use the arm just as usual. After a fortnight, the patient, in constant pain, goes to an old-fashioned practitioner, who promptly puts the arm up on splints and thereby eases its pain—and indefinitely postpones its functional recovery. The original practitioner will be very sore about this, and may regard it as a warning against the dangerous doctrine of massage.

The next group of cases in which I think the mobilization treatment ought to hold the place of honour, and in which it deserves most credit, is in the fractures near joints, particularly in the upper limb, where mobility is of much more importance than strength.

This group includes certain fractures about the shoulder, elbow, wrist, and ankle, and it is in such cases that this method surpasses all others in the greatest degree. But it is very important to define what is meant by 'certain fractures'; and about such definition I am glad to say I have no manner of doubt as regards those who, like myself, are not massage experts. Those cases are to be included in which there is either no displacement, or else impaction in good position, or a displacement which can be reduced into satisfactory position without danger of relapse. And the most simple rule is, that every fracture in these situations should be treated by massage for four to six days (after reduction under anæsthesia if necessary), and no decision to use further measures be made until seeing good *x*-ray photos on about the sixth day. If at this period the end of the bone is in good position, nothing further is wanted; if it is in bad position, some other steps ought to be taken; and if the position is doubtful, the wisest course is to give the benefit of the doubt in favour of the massage. This course can have no danger if the proper treatment is really carried out; because, if it has succeeded, in any of these para-articular fractures, the patient ought to be equal to a complete range of movement in the joint by the end of three weeks; and if he is not, the success of operative treatment will not have been much prejudiced by this short interval.

Another factor which must always be taken into consideration is the likelihood of any alternative treatment being more successful. If the conditions are such that a simple operative procedure, such as the removal of a fragment of bone or the pegging of a single fragment to the shaft in a secure manner, will restore the functions of the joint, this should be done without delay in all doubtful cases; but if, owing to comminution, or the spongy or cartilaginous nature of the fracture area, no simple fixation can be adopted, then the massage method may be pursued with the greater confidence because we need have no anxiety about the neglect of some better way.

Lastly, we come to those cases of fracture, whether of the shaft or articular ends of the bone, in which there is gross displacement persisting in spite of massage or attempt at reduction under an anæsthetic. By the term 'persisting,' I mean that the displacement is present after four to six days' treatment. Such cases have often been treated, without regard to the deformity, by continuation of massage, with quite perfect functional results; but I think that all the weight of evidence goes to prove that such a result is the exception and not the rule. There are only two circumstances which in my opinion justify the ignoring of gross deformity in a recent fracture. The one is that for some reason or other we cannot successfully reduce it either by manipulation, operation, or extension; and the other, that the patient refuses to undergo the alternative treatment, and having seen the x-ray picture, is willing to continue the treatment by mobilization. Under either of these circumstances, I would repeat, at the risk of reiteration, that although we cannot look for anything like a perfect result, we have far more chance of getting a fair and speedy return of function by massage than by long immobilization on a splint.

Note.—In concluding this chapter, I should like to express my indebtedness to Dr. Mennell, both for his personal explanations and the knowledge derived from his book, to which I would refer readers for a much fuller account of this part of my subject.

CHAPTER III

EXTENSION BY ADHESIVE APPLIANCES

WHEN the bone of a limb has been broken completely, the displacement of the fragments is due to the action of three forces—that of the original trauma, the action of gravity, and the tension of the muscles with the other soft parts. When an attempt is made to reduce this displacement, the results of the trauma and of gravity may be counteracted easily by a force of suitable amount and direction; but there remains the ever-present vital force of the muscle-pull to be reckoned with. Under deep anæsthesia the muscles become relaxed, and approximate reduction may be brought about; but immediately consciousness and sensation return, the muscles react reflexly to the very painful stimuli of the damaged nerves, and undergo powerful spasmodic contraction, which usually is sufficient to displace the bones within a very short period.

We must, therefore, regard the pull of the muscles as the great and dominant factor in the situation, the overcoming of which is the chief element in the fracture problem. As we have seen, the 'massage' method overcomes the muscle-force by soothing the muscles, and the operative method overcomes it by a firm fixation of the bones; but there is a third alternative, a *via media*, more certain and more precise than 'massage,' and easier of application than operation. This is the extension method, which has now been employed for many years for special fractures, but has been exalted into a universal system by the painstaking genius of the late Professor Bardenheuer. The extension method directs all treatment primarily to the counteraction of the muscle force which causes or maintains the displacement.

THE ESSENTIAL PRINCIPLES OF EXTENSION TREATMENT.

There are three principles of cardinal importance to be observed in the application of the extension method, viz. :—

1. That the main factor in the restoration and maintenance of the form of the bone is a longitudinal force pulling in the axis of the limb.

2. That this force is to be applied in such a way as not to interfere with the movements of the joints.

3. That passive and active movements of the limb should be practised from a comparatively early period, and before the extension force is removed.

The first is the most important of these principles, and requires a short consideration. In the accompanying diagram (*Fig.* 16) is shown a typical position of a fractured bone, in which are seen the three common elements of displacement, viz., overlapping, lateral displacement, and angulation. Now it is evident that sufficient force acting in the direction of the arrows will correct all three of these errors. The direct pull lengthens the bone until the fragments no longer overlap, and the angulation and lateral displacement will be abolished because the bone tends to assume a straight line in obedience to the extending forces, the straight line being the shortest distance between the points of application of these forces.

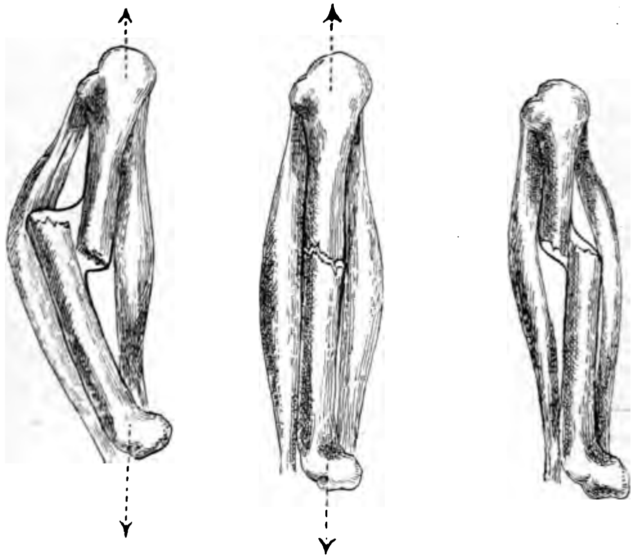

Fig. 16.—Diagram illustrating principles of extension. In the first figure the bone fragments are displaced ; in the second the displacement has been corrected by traction in the direction of the arrows and by the elasticity of the attached periosteum, which is shown as a dark line. In the third (right-hand) figure is shown the possibility of full restitution of length without correction of lateral displacement.

The act of restoration of form by this means usually requires that extension be carried out to such a point that the broken bone ends become disengaged, and the bone as a whole becomes actually longer than normal; then by slow stages, as the extending force is diminished and as the scar tissue contracts, the bones come each to each in accurate apposition. *Figs.* 16 and 17 show how extension may completely overcome one element of

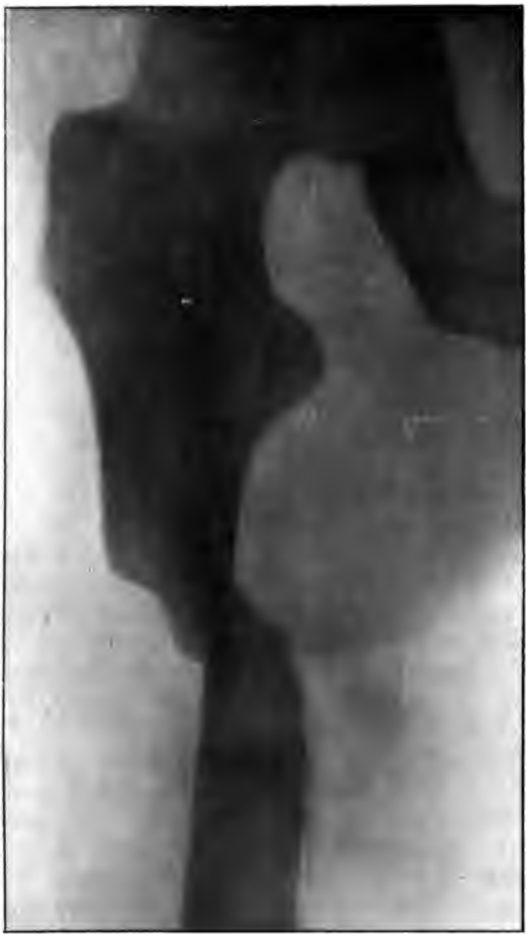

Fig. 17.—Fracture of the upper third of the femur treated by extension, with complete restoration of length, but with lateral displacement remaining, because extension has not been powerful enough for the distraction of the fragments.

displacement, viz., the shortening, without affecting either angulation or lateral displacement, and these will frequently remain if the extension is not pushed far enough to produce actual distraction of the broken ends from one another.

The final accuracy of reposition will depend largely upon the integrity of the soft parts surrounding the bones, especially the periosteum, and it will also require that rotation of any sort be corrected.

There is another most important fact to be considered, that is, interposition of soft parts between the fragments. This, no doubt, is one of the chief and most important causes of delayed union and of false joints. Any attempt to replace the fragments by direct and immediate manipulation is liable to the risk of entangling the torn periosteum and muscle fibres between the bone surfaces. But if the bone ends are slowly and steadily pulled apart, and are actually separated from one another, all the soft parts will be put on the stretch so as to be drawn clear out of the line of fracture. Then the space between the bone ends becomes filled with granulation tissue, which still further pushes out any overlapping tags of periosteum, and it is not until after this has been accomplished that the bones finally become united to one another by callus.

It will be readily understood from the above considerations that the restoration of bone form by longitudinal extension is of the nature of a delicate and complicated adjustment: that the method, unless very carefully applied, is apt to fail. Its success will depend largely upon the circumstances of the case.

The more important conditions which should determine its use are briefly as follows :—

1. *The Youth of the Patient.*—In children and young adults, not only is the muscle tension less strong, but the soft parts, and especially the periosteum, are more elastic, and therefore exercise a greater influence in restoring the alignment of fragments than is the case in older subjects. The very facts that the periosteum in children is thick, elastic, and easily stripped from the bone, prevent complete rupture of this membrane. The bone breaks, and its ends may become displaced laterally inside the periosteal tube, or the jagged ends may tear through the periosteum, while the latter splits and strips from the bone, but retains its connection with it. Under these circumstances it is only necessary to pull the bone fragments apart firmly, slowly, and for a sufficient time, and the periosteum will again form a

tubular sheath, and the area where it was torn from the bone will rapidly pour out callus.

2. *The Limb Affected.*—The arm bones are in reality much better suited for the extension method than those of the leg, although the impression derived from common practice is the exact reverse. My reasons for this assertion are: that the arm muscles are much less powerful than those of the leg; and that the extension can readily be applied to the arm whilst the patient is up and about, whereas in the leg it usually requires that a long period of time should be spent in bed.

3. *The Nature and Position of the Fracture.*—In general terms, the fractures which require extension are those too complicated for massage alone and yet unsuitable for operation. The latter factor requires a discussion of the conditions which make for operative success, which will be dealt with more fully in a later chapter; for the present it is sufficient to say that when the fracture presents great mechanical difficulties to operation, or when the general condition of the patient, or lesions of the soft parts, make operation undesirable, these cases are to be treated by some form of extension. In particular, I would instance gunshot injuries—comminuted fractures of the head of the humerus or femur, particularly the latter—as exemplifying my meaning. Here direct suture is impossible because of the complexity and friability of the parts; but with proper extension they will fall into good alinement, and callus union is rapid.

The second principle, having to do with the means by which longitudinal traction is exerted on the limb, belongs, perhaps, to the detail rather than to the principle of the method; but it must be made quite clear that the application of the force must not involve any rigid splinting of the limb, but that all the joints are to be free to move, and the surface to be massaged, without interfering with the extension.

In England and America it is very common for a type of extension to be used which utterly violates this principle, and by bandaging to a long rigid splint, minimizes almost to vanishing point the action of the extending force. Even the greatest of all extensionists, Bardenheuer himself, tends sometimes to sacrifice the value of his extending force by the complexity of the arrangement for lateral forces or by the mere keeping of a limb on the bed.

The action of the extending force will be efficient in proportion to its amount, its direction, and also the freedom from resistance. Thus, if a limb be hung quite clear of the bed, it will be subject to all that component of the extending force which acts in the axis of the limb ; but if the leg is allowed to lie on the bed; only a part of the force acts upon the limb, the rest being lost in friction ; and still more if the leg is tied to a splint and then laid on the bed is the action of the weight lost as far as extension of the bone is concerned.

But it must not be supposed that the extension principle is inconsistent with the use of splints. Prof. Bardenheuer's splints are indeed the most perfect and the most complicated that have ever been devised. A splint like Hodgen's is in reality only a cradle for the limb and a handle for pulling upon the extending force, and in no way imposes rigidity on the leg, nor does it interfere with extension. The splint ought only to be an accessory, and not an antagonist, to the extension.

The third principle of the method is to leave the joints free so that they can be moved early in the course of treatment. This, though a different principle from the last, is nevertheless attained by the same means, that is, by avoiding the application of rigid splints and the fixation of joints.

It differs from the 'massage' method in the movements being applied later, and in these movements having at first the control of the extending force to prevent displacement. Thus, in a fracture of the humerus, in the extension method elbow movements are not begun until about seven days after the accident, and the weight is not removed from the arm when first passive movements are initiated.

In this respect this method is the middle course between the early movements of the 'massage' school, and the very long immobilization of the 'orthodox' splint method and of too many operative systems.

It probably does not attain so rapidly such perfect function as 'massage,' but it does do this in a longer time, and at the cost of more pain, without so much risk of displacement, in the hands of an unskilled practitioner. At the same time it certainly avoids the danger of loss of function involved by immobilization.

Supplementary Principles in the Extension Method.—In reality these are additions to or deviations from the cardinal principle of longitudinal traction as being the most important agent in reducing and preventing recurrence of bone displacement. But because they appear so largely in the work of the Cologne school, they must be noticed here.

Whilst longitudinal force acts directly upon longitudinal overlapping, it acts only indirectly upon lateral or rotatory displacements. Therefore Bardenheuer found it necessary to supplement his main longitudinal force by transverse and revolving pulls, and in all his appliances provision is made for:

a. Pull in the axis of limb in distal direction.

b. Pull in the axis of limb in proximal direction, i.e. counter-extension.

c. Transverse pull of either fragment from side to side.

d. Transverse pull of either fragment in antero-posterior direction.

e. Rotatory pull of one or both fragments.

It was thus a common thing at the Bürgher Hospital to see a patient with as many as four or even six weights attached to his leg and body and hanging over the sides and ends of the bed.

These additional forces naturally greatly complicate the method; the necessity for their use suggests that the cardinal, i.e. the longitudinal, force is not acting efficiently: and a method requiring all these complications, properly adjusted in relation to one another, can only be carried out by one who has had very special experience in its use. I would therefore urge strongly that the use of anything but a longitudinal extension with proper counter-extension should be regarded as only exceptional. The action of these subsidiary forces ought to be rendered unnecessary, either by a more efficient use of the longitudinal force, or by applying that force in a direction which will abolish lateral or rotatory displacement.

For example, in the upper third of the femur, angulation outwards often persists in spite of longitudinal traction when the leg lies on the bed parallel with its fellow. But if the leg be slung in a position of flexion and abduction this will be corrected, and there is no need of any lateral or front-to-back pulling of fragments.

If, however, simple longitudinal traction in a proper direction cannot accurately replace the deformity, then the case is one for some other method.

The Difficulties and Disadvantages.—Even when those complicated cases which require lateral and rotatory pulls are excluded from its application, the extension method has certain disadvantages.

The principle of the method is that of the establishment of an equilibrium of forces. The muscular force which produces or maintains displacement is opposed by the extending force which overcomes it. But there is good reason to believe that by pulling against a muscle the contraction of the latter is

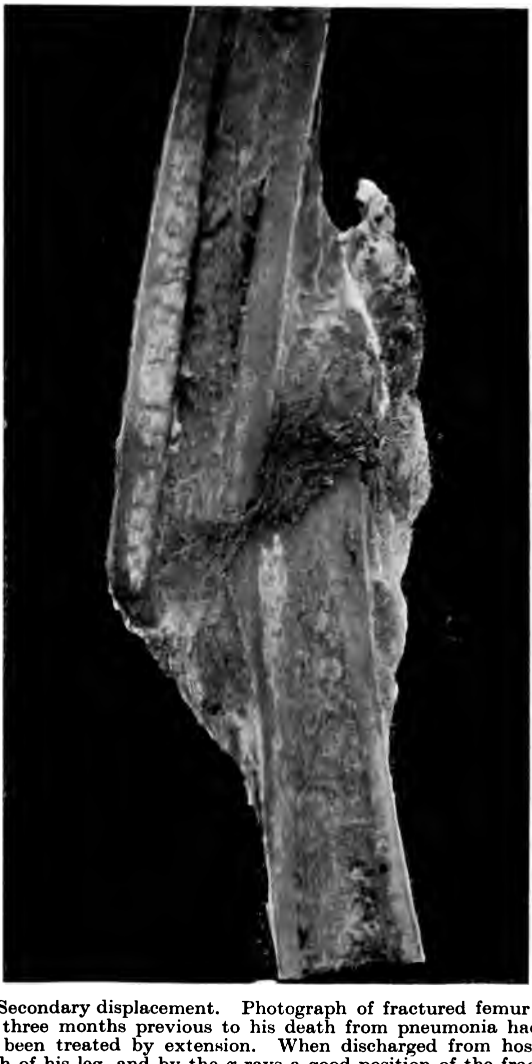

Fig. 18.—Secondary displacement. Photograph of fractured femur from a man, age 51, who three months previous to his death from pneumonia had broken his leg and had been treated by extension. When discharged from hospital he had the full length of his leg, and by the x rays a good position of the fragments ; but subsequently the fragments have become secondarily displaced, and they are merely united by fibrous tissue, which is only partly ossified. (*From a specimen in the Royal College of Surgeons' Museum.*)

augmented, or it may actually be thrown into spasm, so that the extending force has often to be great enough to counteract not only muscle tone but muscle spasm. The extending force has to be applied to the displaced bone indirectly through the skin, fascia, and ligaments. All these structures, being soft and elastic, take up a good proportion of the force, and this is another reason why this force must be very great. The application of this powerful force by means of adhesive plaster requires not only a sound skin, but one which is also healthy and resistant. When there is an external wound, or when bullæ form beneath the epidermis, the extension plaster cannot be applied, and effective treatment must be delayed until the skin surface has recovered. But this delay, with the consequent shortening, will greatly add to the resistance to be overcome.

For these several reasons the method demands the use of a very considerable extending force, varying from 10 lb. for the arm to 50 lb. for the thigh of an adult. But the use of such weights, even for a few days, is a cause of much pain, and in this country very much smaller ones are used—perhaps 8 lb. for an arm or 20 lb. for a leg representing a maximum; in fact, the practice which is often followed is based on the idea that only the maximum weight should be used which will cause no pain. This idea, in the extension treatment of fractures, is erroneous. It is correct in the treatment of the deformity of a tuberculous joint, where only adhesions, contracted ligaments, or atrophied muscles require to be stretched. But in a fracture, where vigorous muscles have to be pulled against their own spasmodic contraction, it is inevitable that this should cause pain. Certainly in this method the absence of pain cannot be held to be a test of efficient application. Only one thing constitutes such a test, and that is an *x*-ray photograph.

Another disadvantage and uncertainty of extension treatment of all forms is the possibility of late or secondary displacement (*Figs.* 18, 19, 20, 21). The broken bone ends are often held in good alinement, but not in close apposition. This means that there is a large gap to be filled up by reparative material. Such repair-tissue undergoes ossification in the adult very slowly, and probably at the end of six or eight weeks it is generally largely fibrous and therefore plastic. But at this period, and long before it in most cases, the extension has been lessened or removed and the limb is used. Thereupon the muscular tension slowly deforms the seat of fracture, so that the final result is

Three skiagrams illustrating the liability of the femur to secondary displacement. From a man, age 42, who refused operation for his fractured femur, and was treated by extension.

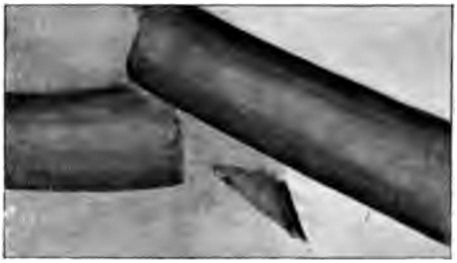

Fig. 19.—Within one week of accident.

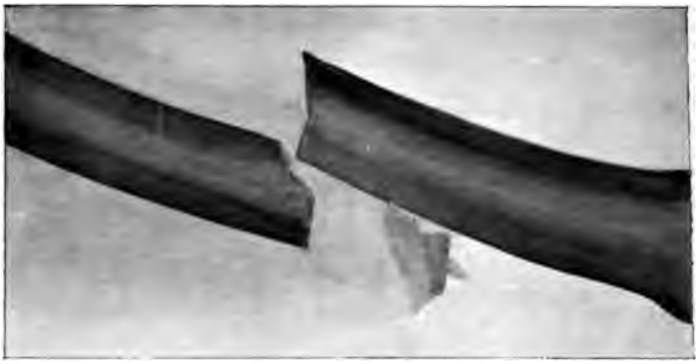

Fig. 20.—After fourteen days' extension.

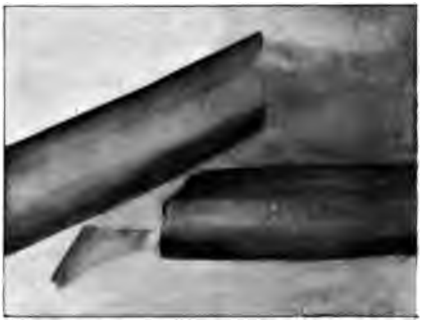

Fig. 21.—Three months later.

very far short of that which the x-ray picture may have promised earlier in the course of treatment. This late displacement is especially liable to occur in the femur of adults, in the case of oblique fractures, and in those where the extension has never quite corrected the lateral deviation.

It is a matter of opinion as to the frequency of occurrence of this late displacement, but it may be taken as a safe rule that a poor position of the bones attained by extension will become worse eventually, and not better; therefore the practice to be followed is, that if extension can easily produce a good position within one week of its application, the method is satisfactory; but that if it requires a very great weight, many secondary forces, and then at the end of a week the position is poor, it had better be abandoned for something more efficient.

Having now laid down the principles concerned in the proper application of extension to fractures, it remains to describe the most convenient methods for carrying out these principles. We must reckon with the important fact that the great majority of those who have to undertake the treatment of fractures do so without any knowledge of mechanical principles or of their application. Therefore everything must be of the simplest possible character, requiring as little adjustment as possible; the necessary mechanical principle must be embodied in the apparatus itself, and not supplied by the person who adjusts it.

THE TECHNIQUE OF THE PLASTER EXTENSION METHOD.

In one form or another, plaster extension has been in universal use for many years, and therefore it would seem quite unnecessary to describe its application. But unfortunately, speaking from personal observation, it is evident that the importance of certain details have been quite overlooked, and I think therefore that it is necessary to emphasize these details in order that it may be understood clearly what is meant by the 'extension treatment.'

In the following description I follow Prof. Bardenheuer's technique except where otherwise stated.

The Application of the Extension Plaster.—Two kinds of plaster are needed: One is a very strong strap about two to four inches wide, spread with zinc oxide plaster, which is laid along the length of the limb; the other a quite thin rubber plaster, used in circular turns to bind the long strips in place. Some difference of opinion exists as to the necessity of shaving the limb; but it seems to me that the plaster can be made to adhere much better and be removed more easily on the shaved limb, and therefore I advise that shaving should always be a preliminary, especially in very hairy limbs.

The joints are left free from any circular turns, and the longitudinal strips are prevented from adhering over the joints, either by the insertion of gauze, or of small pieces of plaster adhering to the main strips, with the non-adhesive side towards the skin. Thus, in the leg, the knee and ankle should always be left free, so that movements at these joints shall be unrestricted. Prominent subcutaneous bone edges must be protected by a layer of gauze before the circular strips of plaster are applied, e.g. the anterior border of the tibia is so covered.

The plaster must always be applied right up to the proximal part of the limb, or at any rate up to the joint above the fracture. Bardenheuer carries this principle to the extreme point; in the case of a malleolar fracture, for example, he applies the extension plaster right up to the level of the great trochanter. In this it is difficult to follow him, because the skin and fascia must in this case have far more connection with the bones proximal than with those distal to the fracture, and therefore most of the extending force must be pulling on the proximal part of the limb. But there can be no doubt as to the necessity for applying the plaster up to the level of the joint above the fracture, and not simply up to the level of the fracture itself. Take, for example, a fracture of the lower third of the femur. Plaster which stops at the site of fracture can only pull the lower end of the muscles of the thigh, and the extension force will have to overcome the whole resistance of these muscles and of the elastic retraction of the skin and fascia. But if the plaster is applied to the top of the thigh, then it will directly pull the whole tube of soft parts, skin, fascia, and muscles, together with the lower fragment, down over the upper fragment.

When the plaster has been applied, and provided with the usual stirrup or buckle for the attachment of the extending force, the limb is surrounded by bandages, except over the joints, and then, without any splint, is loosely slung over the bed, and the weight attached.

It may be well to point out the way in which these details are commonly violated in the application of extension, and the result which follows. The plaster is generally put on only up to the seat of fracture; by this only a small area of skin serves as the point for the application of the extending force, and no grasp is afforded upon the tube of soft parts above the fracture; this results either in the plaster slipping, or in the fracture not being reduced. The long strips of plaster are often attached only by their own surface and by two circling strips, instead of by the use of the finer type of plaster applied to the whole limb with the exception of the joints; this, again, gives a very insecure hold, and instead of the encircling plaster giving uniform support and pressure by which œdema is prevented, the two strips hinder circulation, and cause an œdematous swelling between their points of application. The joints are not left free from adhesive plaster, nor are the bone points protected; consequently, movement is difficult, and the skin becomes sore over the bones. Lastly, one or more long rigid splints are applied to the limb over the plaster, and by this means not only is the essential mobility of the joints lost, but the power of the extending force is very largely counteracted. It is quite obvious that any extending force will act at the greatest advantage if the limb is left free from either lateral forces or rigid splints, and the latter ought only to be used as a means of applying the extension force, and not as a supplement to its action.

The method of extension cannot be described as specially modern, and it is quite out of place here to go into all the details of its application. But it is, I think, modern in the sense that it cannot be discarded or superseded at the present time in certain classes of fracture. It will be well, therefore, to consider those methods of its application, both in bed and by ambulatory methods, which it is still necessary to practise, even when massage and open operations are freely used.

PLASTER EXTENSION (IN BED) FOR FRACTURES OF THE LOWER EXTREMITIES.

FRACTURES OF THE FEMUR.

Vertical Suspension.—The simplest and most successful method of plaster extension for broken thighs is that of vertical suspension. This is commonly used in the case of infants; but probably there is a tendency to restrict it too much to very young patients, and it may be applied with excellent results to children up to ten or twelve years of age. It is necessary first to provide a firm cross-piece at a suitable height above the bed.

This can be made of wood by a carpenter at a moment's notice; in some cases it will be more convenient to fit it on to the bed frame itself, and in others to allow it to stand on the floor. To the cross-piece are fixed either hooks, pegs, or pulley-wheels for the attachment of the extension cords, and nothing is better than a series of brass pegs which will allow of different degrees of abduction. It is much better to tie both legs by the extension cords to the cross-piece than to apply a weight extension by pulley-wheels. The extending force is the weight of the child's body, and if weights are used, it is difficult to adjust them so as to just counterbalance the body weight.

The strapping is applied to both legs according to the rules given above. The legs are then fixed to the cross-bar, with abduction of about 60°. This abduction is important, because it corrects the invariable tendency to adduction, and also because it makes it easier to keep the child clean. The amount of suspension should be such as just to lift the pelvis off the bed, and it is important to see that the nurse does not vitiate the whole arrangement by tucking in a pillow beneath the buttocks. The position is maintained for four weeks, after which the strapping is removed and the child walks with a thick-soled boot on the good leg, with the help of crutches for two weeks. After the first week, both knees are exercised daily. This is done by one person holding the thighs just above the joints so as to keep the child off the bed, while another loosens the extension cords and flexes the knees.

Suspension in the Semiflexed Position.—Extension applied by adhesive plaster for fracture of the femur in adults requires great care and judgement in its application. It is of most value in those patients who refuse operation, in fractures without much displacement, and in fractures near the neck of the femur which are difficult to operate upon. Bardenheuer speaks of using 25 kilos (55 lb.) for the extension of fractured femurs. But in his system the leg lies upon the bed, and has other lateral forces applied to it, all of which absorb a good deal of the main force. In this country, I have never yet met a patient who could bear anything like this amount of weight, and 25 lb. I regard as the usual limit. In order to obtain the maximum benefit of the extension, three points must be observed :—

1. The limb must be abducted, countertraction of the pelvis being maintained if necessary, by a padded band round the perineum and opposite thigh, fixed to the upper bed-post

on the side of the sound limb. The maintenance of abduction is perhaps the most important factor in preventing deformity and lameness, especially in all fractures at or above the upper third of the femur. This is partly because of the prevention of internal deviation of the axis of the femur, and partly because the adductor group of muscles, having no physiological opponents attached to the shaft of the femur, require to be counterbalanced.

2. Flexion of both joints—the hip and the knee. In practice it is found that a position of semiflexion is the best, and certainly the most comfortable for the patient. The reason for this position is that it leaves the powerful hamstring muscles slack, and by so much lessens the extension force required to overcome shortening.

3. The limb should be swung clear of the bed. This will allow of the full extension force operating so as to reduce the fracture and maintain reduction; it will ensure that the extension force is acting in the line of the axis of the femur, undeflected either by splint or the mattress of the bed; and it will allow the toilet of micturition and defæcation to be carried out without interfering with the treatment.

These three principles, viz., abduction, semiflexion of hip and knee, and free suspension, can be carried out in various ways. Either the leg can be slung to a longitudinal bar above the bed, or it can be laid upon some kind of a trough splint on a fixed base, or a Hodgen's splint may be applied. This latter acts as a suspensory cradle and as a means of attachment of the extension force, and if properly applied is a good means of carrying out the plaster extension method on the thigh. In the original design of Hodgen's splint the weight of the suspended leg acts as an extension force. But I think that where it is necessary to apply a big extension, it is better to suspend the splint in any convenient manner, and then to apply the necessary weight running over a pulley in the axis of the limb. This ensures a more accurate force being employed, for according to the original plan the effective extension will always vary with the angle at which the leg is suspended.

The amount of weight to be employed is a matter of very great importance. All are agreed that only the least amount that will effect the desired result should be used, but there is a wide difference of opinion as to what this is, and how it is best applied. In this country the weight employed is generally quite inadequate, 10 or 15 lb. being the maximum—simply because more causes pain, and it is assumed that the maximum weight which can be employed without pain is sufficient. But *Figs.* 17, 19, 20, 21, demonstrate the futility of this plan. Moreover it is usual to begin with a small weight, 7 or 8 lb., and then gradually increase it. Bardenheuer, on the other hand, applies a relatively enormous weight of 50 lb., and the patient must suffer great pain; he often gets a looseness of the joints as a consequence of the long-continued excessive force.

If we consider that the object of the extension is to overcome muscular action, it will become evident why so much force is necessary, and why it is so painful. The muscles of a broken limb are contracted in a tonic manner. When they are pulled upon they contract yet more, and are often thrown into spasm. Hence the force necessary to overcome muscle resistance must be just enough to counteract active muscular contraction, and not mere passive tone. Naturally this will cause pain. If the case is not treated for some days or weeks after the accident, there will be all the passive resistance of the exudation tissue round the fracture to be overcome, in addition to the muscle force. Anyone who has operated upon a fractured femur with much overlapping of the fragments will appreciate the enormous force which is required to effect reduction. If these premises are granted, it will be apparent that to effect and maintain reduction by extension without an excessive weight and great pain, it will be necessary to act in a different way from that of gradually adding to the extending force.

At the very outset, when the plaster extension has been applied and the method of suspension decided upon, the patient should be fully anæsthetized, and traction made upon the limb by means of a towel passed round the thigh above the knee. Such traction with the operator's full power, and with the assistance of good counter-extension, will give a force of between 100 and 200 lb. This is kept up steadily for about fifteen minutes, or until it is quite clear that the ends of the bone are separated from one another. Then a weight of 20 or 25 lb. is applied, and the limb is slung in its permanent position. A full dose of morphia is given before the patient has recovered fully from the anæsthesia, and in this way the pain of the extension is reduced to a minimum. By this method the muscles and exudation tissue are stretched once and for all, and the pain rapidly passes away. The comparatively small weight is then enough to maintain the position without evoking further painful muscle spasm. The analogy of the dilatation of the sphincter ani may be quoted in illustration of this principle. When the anus is forcibly dilated under an anæsthetic, it remains lax and paralyzed for some time afterwards; but if an attempt were made to dilate it by a gradually increasing force, without an anæsthetic, this would produce intolerable pain and spasm.

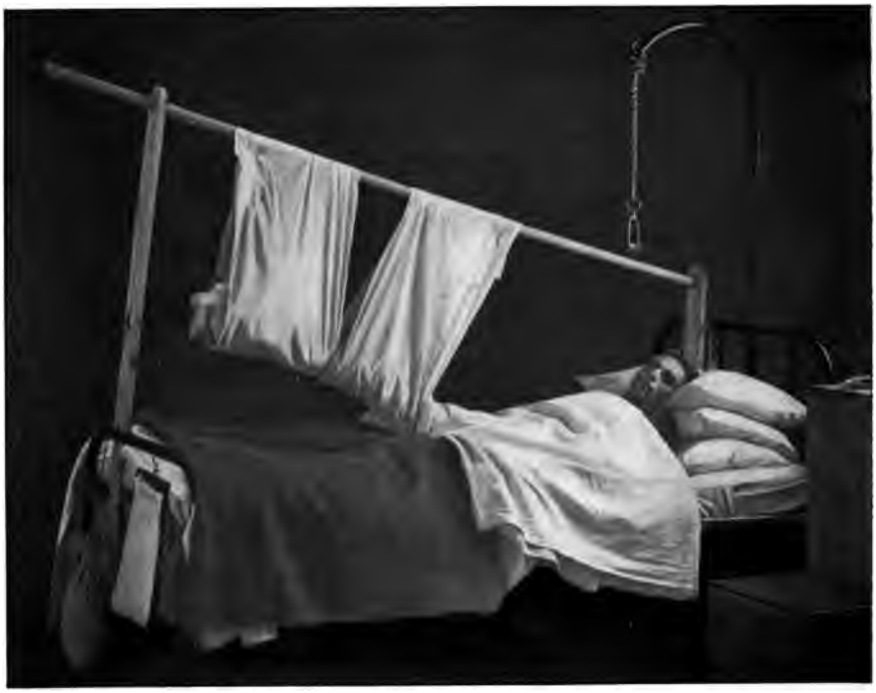

Fig. 22.—A simple method of suspension and extension of the leg. Patient from the 2nd Southern General Hosiptal with gunshot wound and fracture of neck of the femur. The uprights which support the horizontal bar can be attached to any bed. The pulley can be adjusted in height. The weight shown is 12 lb. of sand.

SPECIAL APPARATUS.

The Leg Sling Extension (*Fig.* 22).—This, commonly known as the Balkan splint, has the merit of requiring no apparatus which cannot readily be supplied by any hospital with the aid of a carpenter. An ash pole, such as that used for broomsticks, is fixed above the bed, resting in sockets in wooden uprights which are screwed by metal clips to the upper and lower frames of the bedstead. The foot end of the ash pole is 12 in. higher than the head end, so as to be in the same line as the elevated leg. The wooden upright at the foot has a pulley wheel which can be adjusted to any height. The plaster strapping for the weight attachment is fixed to the leg, and then the limb is slung at a convenient height from the bed, with the hip and knee in a semiflexed position. The sling consists in its simplest form of a piece of roller towelling pinned over the bar. But if the case be one of open fracture which has to be dressed often, it is more comfortable to provide a cradle of poroplastic, sheet zinc, or Gooch splinting, which is slung by two pieces of webbing and adjusted by buckles. It is very important with this, as with other similar contrivances, to secure adequate counter-extension, either by raising the foot of the bed on eight-inch blocks, or by means of a perineal pad and cord attached round the crutch of the sound leg and tied to the bed-head. If the fracture be above the middle of the femur, it is important to put the leg in an abducted position from the outset. The pole is placed diagonally across the bed, the foot end being over the corner on the side of the wounded limb, the head end being over the opposite upper corner. To enable the bar to be placed in this position, the sockets in the uprights must be cut so as to give ample lateral play. It is prevented from slipping out of these sockets by a small transverse wooden pin.

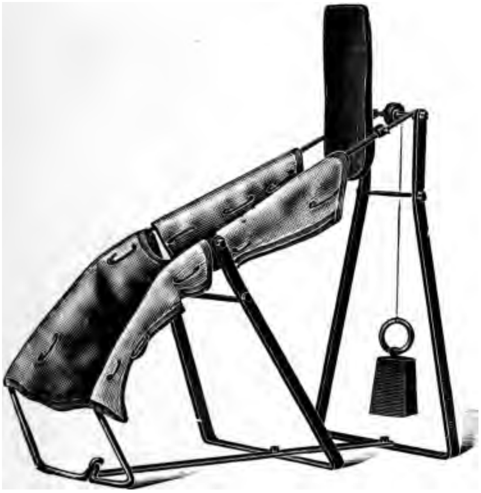

Fig. 23.—Wire cradle leg splint, with slings in position.

The Wire Cradle Splint.—The accompanying illustrations (*Figs.* 23, 24), show the general construction of this. It stands firmly upon the mattress of the bed, supported by fracture-boards. A sand-bag placed inside its base will secure it further from any jolting. The leg is slung in a cradle made with strips of calico or house-flannel pinned round the wire frame. Extension may be applied either simply by adhesive plaster, or when a wound low in the leg prevents this, by a wooden foot-piece which slides on the frame. The extending force is a weight running over a pulley at the end of the splint. I believe that this is the most satisfactory form of sling support for extending a broken leg. It is all ready for adjustment at a moment's notice; any part of the limb can be exposed for wound dressing without disturbing the fracture; by placing a rubber sheet inside the sling it makes continuous irrigation of the wound very easy in open fractures; it is easy to cover over the whole leg with the bed-clothes and so keep the limb warm; it allows passive movement of the knee with great freedom, the extending cord being merely lifted off the pulley; and finally, it requires almost no adjustment when it has once been put up.

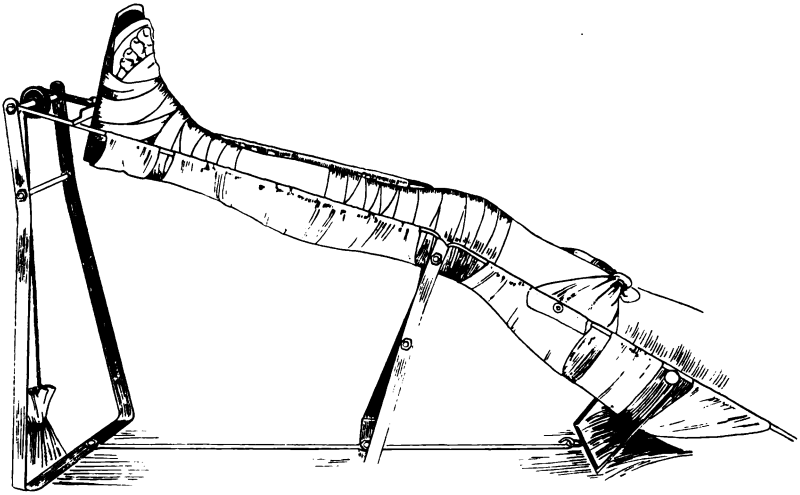

Fig. 24.—Author's wire cradle splint in use.

The Thomas Knee Splint.—Mr. Robert Jones has always strongly advocated the advantage of Thomas's knee splint for the treatment of fractured femur. It acts then as an extension frame. Mr. Jones merely pulls the limb down and then fixes it to the cross-bar of the splint by special bands and strapping. There are certain objections to the splint used in this way for adults. These are: that the metal ring, however well padded, is not comfortable to lie upon and is liable to make the perineum sore; there is no provision for a continuous extension pull—it merely keeps the limb in the position into which it has been pulled by the operator; it does not provide for the joints being semiflexed, neither does it allow of passive movements of the joints during treatment.

Most of these objections can be met by modifying the form of the splint, the modifications being as follows:—

1. The ring which encircles the upper end of the thigh is incomplete behind—in fact it is a horseshoe and not a ring; the gap is closed by a piece of stout webbing with a buckle which keeps it in place. This can be more easily applied than the simple Thomas knee splint, as the horseshoe is slipped over the front of the thigh, instead of the whole leg having to be passed through the ring. When in position, the patient does not have to lie upon the ring.
2. There is a joint provided in the splint, opposite the hip, to enable the leg to be raised from the bed for the dressing of a posterior wound.
3. There is a spring with a screw adjustment at the lower end, by which 20 to 30 lb. continuous extension can be maintained.
4. In one form of this modified splint there is a joint opposite the knee, so that the limb can be put up with semiflexion of both hip and knee-joints.
5. The splint is provided with a metal support which rests upon the bed and thus prevents rolling of the limb; this also ensures that the leg is slung free from the bed.

I do not believe that even in its modified form such a splint is either so comfortable, so easy of adjustment, or so efficient as the wire cradle described above, but it is especially well adapted for maintaining extension in a good position during transport of wounded soldiers, if they have a long distance to travel.

The Jones Abduction Frame.—Mr. Robert Jones writes (*Brit. Med. Jour.*, Jan. 16, 1915, p. 101): "Fractures through the hip-joint and those just below the trochanter, are best treated by a modification of the Thomas splint, which I have described as an 'abduction frame.' It is a splint upon which the patient lies and can be carried. Extension is easily maintained and applied, and need not be relaxed for any purpose. The patient is placed upon this splint, and any displacement should be overcome by immediate extension in the abducted plane. The limb should be rotated inwards slightly, until the foot is at right angles to the table, and be fixed in this position on the frame. It will be seen by the illustration that both limbs are controlled, and that extension is secured by strapping on the injured limb, with counter-extension by means of a smooth leather groin strap on the opposite side of the pelvis. This groin strap should not be slackened by the nurse under any pretext; but in order to avoid pressure sores, she should be instructed to alter the area of skin over the adductors which is subjected to pressure, by moving it to and fro. This method of 'fixed extension' in abduction secures the lower limb in relation to the pelvis in a manner which can never be satisfactorily achieved by weight and pulley, where reliance is placed on the weight of the body for counter-extension. The patient who lies on an 'abduction frame' can be lifted and moved without pain, without disturbing the fracture or relaxing the extension, and the dressing can be changed without interfering with the mechanism of fixation. If the wound is through the buttock and the discharge takes place there, the splint can be modified as shown in the illustration. The 'abduction frame' can be applied in a few minutes."

I attach so much importance to Mr. Jones's opinion, that I have quoted his own description of this excellent appliance; but I have always regarded the 'abduction frame' as suitable for children only. In the case of an adult man, its great advantage that the patient can be lifted bodily on the splint does not apply; and if sufficient extension be kept on the leg to undo the overlapping of the fragments of a fractured femur, there will be great danger of the perineal band making a sore place, which a nurse is likely to overlook.

Fractures of the Leg.

These can be perfectly well treated by any of the appliances described above, viz., the sling, the wire cradle splint, or the modified Thomas splint. But they can also be efficiently extended by means of a much simpler and less cumbersome apparatus. This consists in a wire frame which goes down each side of the leg from the knee, and is bent at the knee to support that joint about 12 inches above the bed. The leg is slung by strips of bandage to the metal frame, whilst a similar strip above the knee gives counter-extension by supporting the thigh. The extension is effected by a spring rubber band, or by a weight over a pulley at the lower bar of the splint.

The method of attachment of the extension to the leg must depend upon the presence of a wound and the soundness of the skin. If the skin is quite whole, the leg is shaved and strapping applied along its lateral surfaces in the usual manner. The lower ends of the strapping are fixed round a wooden sole-piece, slightly hollowed to take the heel. This has a metal bar screwed to its under surface, with a ring for attachment of the extension cord (*Fig.* 25). This metal bar stands out for one inch on each side and rests upon the side-bars of the splint, running upon these with very little friction, but serving to prevent the foot from rotating inwards or outwards.

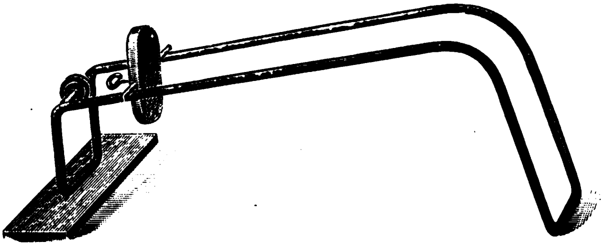

Fig. 25.—Author's wire cradle Leg splint. It is made of $\frac{5}{16}$-in. mild steel wire, bent at 110° at the knee. The thigh part is 12 in. high and 10 in. wide, the leg piece is 26 in. long, and the lower end is 5 in. from the supporting board.

If there is a wound, or the skin is much bruised, the extension can be applied by means of a boot with a wooden sole and a soft 'upper' made to lace over the foot.

PLASTER EXTENSION FOR FRACTURES OF THE UPPER EXTREMITIES.

Treatment of Arm Fractures in Bed.—It is comparatively rare to have a simple arm fracture which must be treated in bed; but it is probable that many cases which now are treated with bad results by means of ambulatory methods might have been successfully reduced by a preliminary extension in bed.

The method of the application of plaster extension to the arm needs no special description. *Fig.* 26, copied from Bardenheuer's work, shows the general arrangement. Besides the fact that much more powerful extension can be applied in bed than when the patient is up, there are two positions of great importance which can only be attained in this way, viz., flexion —that is, forward movement—and abduction of the humerus. And in those cases of complete fracture where the upper fragment points forward or outward, it is of great value to extend the distal part of the limb in the line of the proximal. Here again, as in the case of the thigh, a suspension of the limb with moderate abduction is the best possible treatment for fractures at or below the surgical neck in children. After ten days or a fortnight this can be replaced by one of the extension splints described below, or by a simple sling. Naturally such treatment will only be necessary in the minority of cases—namely, when there is much displacement. But it is in the cases unreduced in the out-patient department, and sent up to the ward for operation, that this treatment ought always to be tried before resorting to an open attack upon the bone. The latter should never be carried out until the extension method has been tried and failed. This can be ascertained usually within five days, and such a delay does not interfere with successful operation afterwards.

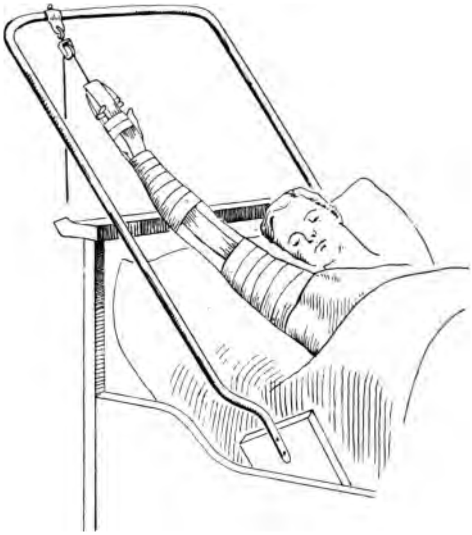

Fig. 26.—Method of plaster extension of arm fractures. (*After Bardenheuer.*)

The Ambulatory Form of the Plaster Extension Method. — It has already been stated that the majority of arm fractures do not require in bed treatment. There are also a certain number of leg fractures in which any ambulatory method will be of very great advantage.

Extension splints have been devised in great number and variety for the arm, and they vary in construction from the complicated apparatus of Bardenheuer or Hennequin to the simple wooden and rubber structures of Borchgrevink. It is not necessary to describe here any but the simplest forms of apparatus, because I am quite convinced that costly and complicated mechanism will never be much used in fracture work, partly because of its expense, and still more because it demands a mechanical instinct or training on the part of both medical men and nurses who have to apply it.

The Y-shaped Crutch Splint.—The simplest form of extension splint for the upper arm is a crutch-shaped piece of wood provided with elastic or spring. This was designed by Borchgrevink, and used extensively in the Balkan war. In the original splint a piece of rubber tubing on the inner surface of the splint pulled upon the extension cord, which passed round a terminal pulley-wheel. I have fully satisfied myself of the excellence of this device from personal experience; but I have been led to modify its construction in certain details, which do not affect its principle, but make it lighter and easier of application.

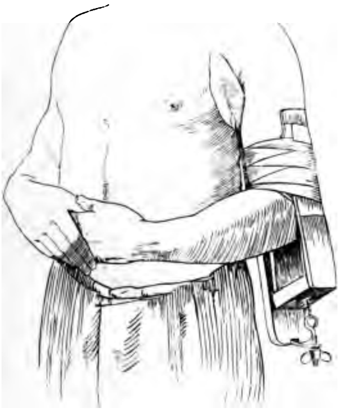

Fig. 27. — The Y-shaped crutch splint for extension of fractures of the humerus. The screw adjustment depicted may be dispensed with, and the spring tightened by pulling on and knotting the cord attached to the wooden stirrup.

Fig. 27 shows the modified form of the humerus extension splint. A light Y-shaped piece of wood, ten inches long and three inches wide in the shank, fits under the armpit, where the padded crutch affords comfortable counter-extension. At the lower end is an L-shaped spring, the outstanding arm of which provides 12 lb. of extension. The amount of extension can be graduated by means of a screw working on a ball washer which allows the extension to act always in line with the axis of the arm.

The extension force is applied to the arm by the usual adhesive plaster, provided with a wooden spreader to prevent lateral pressure upon the condyles. In this, as in all the spring extension apparatus which I use, the limb can be tied to the spring by a simple cord, or more accurately adjusted by the screw and nut.

In most cases it is not necessary to use more than about 5 to 8 lb. extension for arm fractures. In the case of a humerus with much displacement which has been neglected, it is better to reduce this in bed by weight in a position of abduction, or under an anæsthetic, and only apply the ambulatory splint after the gross displacement has been corrected.

This type of humerus extension splint is quite comfortable to wear. The elbow and wrist-joints are free, and the shoulder also is left exposed. All these joints can therefore be massaged and exercised from the outset, and usually at the end of a fortnight the splint can be left off.

Extension Splints for the Forearm Bones.—The simple splint of Borchgrevink's is quite efficient for certain kinds of fracture. It consists of an L-shaped posterior splint, with a pulley-wheel at the end and a rubber extension at the back. There are certain drawbacks in the details of its construction, which can be overcome by the modifications which I have devised. These drawbacks are: the splint is heavy, and the forearm piece with its projecting pulley is very long; the counter-extension, being a mere bandage round the arm, is apt to be uncertain in its action; the splint, though admirably adapted for fixing the arm in supination, interferes with the

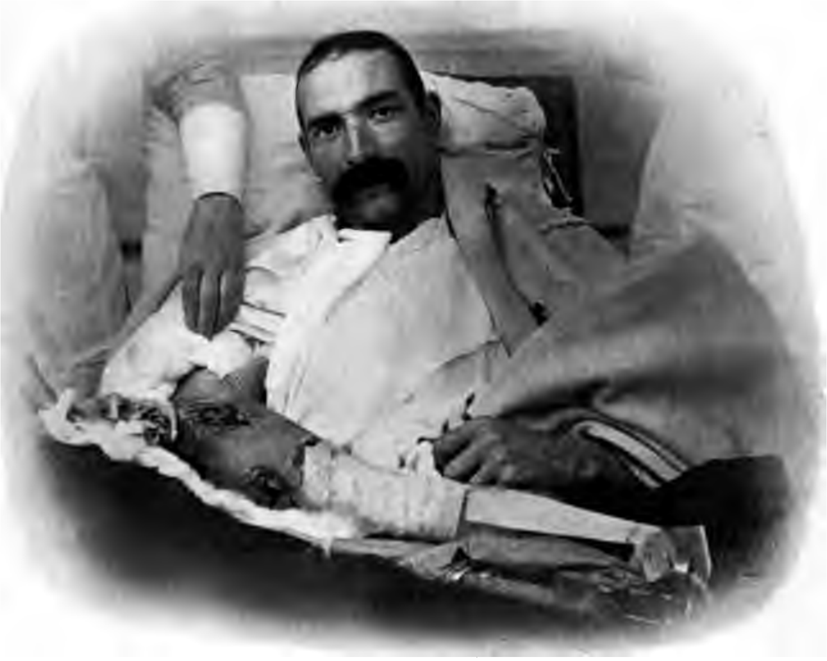

Fig. 28.—The antero-internal splint. A Scotchman in one of the Paris hospitals with fractures of the humerus, just above the elbow, and the forearm. Dislocations of both fractures were reduced by the extension.

dressing of wounds upon any except the flexor aspect of the limb.

The Antero-Internal Splint (*Fig.* 28).—In cases where the arm, and especially the elbow, is much shattered, and large wounds require frequent dressings, an internal angular splint is almost indispensable to form a rest on which the injured limb can lie as the patient is in bed. This is widely cut out at the elbow-joint so that the internal surface of the latter is accessible. A piece of wood projects in front (the flexor aspect) of the upper arm, and this affords firm counter-extension. Extension of the forearm is on the same principle as in the other splints of this type.

The Metal Frame Splint.—For the majority of forearm fractures a light metal frame splint is by far the most convenient.

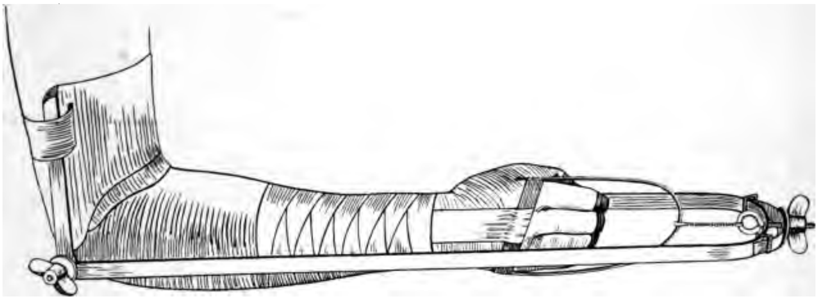

Fig. 29.—Metal frame splint for extension of forearm fractures.

A curved plate rests in front of the upper arm, and two slender metal bars are hinged to this at the elbow-joint and run down the inner and outer sides of the forearm, meeting one another below the hand, where there is a metal spring with screw adjustment. This allows full access to the whole elbow and forearm, whilst all the joints are left quite free and the extension force has full play. When the extension (of about 6 lb.) has been adjusted to the forearm, this and the counter-extension plate keep the splint in position; but any shifting can be prevented by a few turns of bandage round both the upper and lower arms.

Two further points of importance remain to be noticed in the application of extension to the forearm. When I began this method, I followed Bardenheuer and Borchgrevink's practice and attached the adhesive plaster right along the flexor and extensor surfaces of the forearm, hand, and fingers (see *Fig.* 26). This answers the purpose of extension quite well, but it keeps all the finger-joints fully extended throughout treatment, leading to stiffness which takes some time to cure. I now use a little metal frame, as shown in *Fig.* 29, which quite obviates this difficulty. The flat metal band surrounds the hand in the region of the middle of the metacarpals, and to this the adhesive plaster is attached. A ∩-shaped wire runs from one side of this metacarpal band to the other, long enough to clear the fingers.

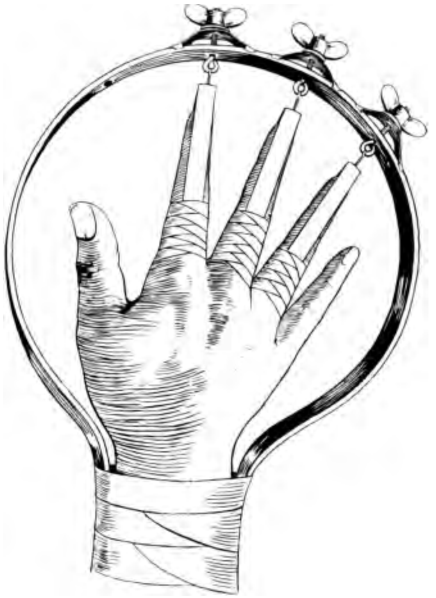

Fig. 30.—Author's extension frame for treatment of metacarpal fractures.

Thus the fingers and thumb are left quite free and can be exercised from the very first.

The next point, which is still more important, is the maintenance of supination. I hold it to be a cardinal rule that in all fractures of the shafts of the forearm bones, supination should be maintained, whether the fracture be in the upper, middle, or lower third. If this point is not attended to, the hand becomes fixed in pronation, and it is a most difficult matter to restore supination. The maintenance of supination is achieved in the metal frame splint by two circular turns of strapping just above the wrist. One passes in front from the ulnar to the radial side and is fixed to the outer bar, the other passes behind in the reverse direction and is fixed to the inner bar.

Fractures of the Metacarpals and Phalanges.—It is but seldom that these injuries require any special appliance for their treatment, but nevertheless, when the long bones of the digits are much crushed and displaced, very great disability may arise from a neglect of suitable treatment. When the *x* rays show much overlapping of the fragments, these ought to be reduced at once by traction under an anæsthetic, and then the hand put up in the appliance shown in *Fig.* 30. This consists in a metal bar which skirts the tips of the outstretched digits. The bar is fixed to a thin anterior splint which is firmly strapped to the forearm by adhesive plaster. A suitable screw spring can be adjusted opposite to any digit, and serves to keep up the requisite extension whilst healing is in progress. The open form of the splint allows the wounds to be dressed.

Chapter IV

MECHANICAL MODIFICATIONS OF THE EXTENSION METHOD

THERE are various objections to the plaster extension method, dependent upon the difficulty of its application rather than upon any fault in its underlying principle.

Of these, the most important is the fact that the extending force has to be applied to the bone through the intermediation of the skin, fascia, and ligaments, and as a consequence of this, the amount of effective force is much limited, so much being taken up by the elasticity of the soft parts. If great force is used, it causes much pain, and will be liable also to stretch the ligaments of any joint which lies between the force and the fracture. If the displacement of the bone is great, and if there are rotation and angulation as well as overlapping, the simple extension has to be supplemented by secondary pulls in various directions, making the method too complicated for ordinary use. If the fracture is near the distal end of the limb, the plaster has but a small area of attachment for effective action. In a word, the plaster extension method is an indirect one, which does not give us complete command of the bone.

It is not that the principle of extension of the fragments is at fault, but only that this extending force cannot be effectively applied by external plaster. And further, if the skin is much injured, or if large wounds are present, it may be quite impracticable to apply the adhesive plaster; and yet to delay until the soft parts are healed will be to wait for mal-union.

DIRECT TRACTION UPON THE BONE BY TRANSFIXION: NAIL EXTENSION.

In 1907, the Italian surgeon Codivilla and the Swiss Steinman independently suggested that by fixing the extension force directly to the lower fragment by means of nails, a much more efficient action could be obtained. At first, two nails were driven into the bone, one from each side, and hence the method is known as the nail-extension method, though now a transfixing pin is generally used in place of the nails, because the latter often quickly become loose when they are pulled upon.

This direct extension by transfixion of the bone possesses the very great advantages of power and accuracy. It will appeal especially to those who have found that plaster extension in many cases is difficult and uncertain.

Two illustrations (*Figs.* 31, 32) will serve to show how a weight which cannot reduce overlapping when applied by plaster, will rapidly do so when attached directly to the broken bone. And not only does the direct extension undo the overlapping, but it causes an actual distraction of the fragments, so that they become separated from one another by a considerable interval. Then, when the weight is diminished, the bone ends are drawn together by the intervening granulation tissue. There is no doubt that in this direct extension we have a more powerful method than any other for the reduction of fractures, and it is therefore of particular advantage in old fractures, not yet united, or in mal-united cases, after the division of the union, before operative fixation. All operators will agree that the most difficult manipulation in the plating of a fracture is the reduction of the overlapping bone fragments, and this difficulty is almost abolished if, three days before operation, direct extension be applied (under gas anæsthesia).

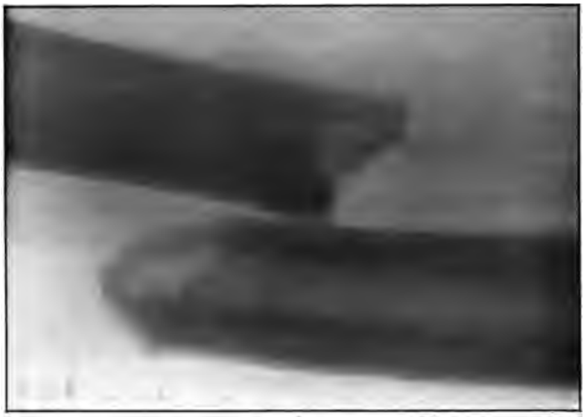

Fig. 31.—Fracture of the middle of the shaft of the femur treated by adhesive plaster extension.

Next to its power, the great advantage of direct extension is its accuracy. The distal fragment of bone can be pulled in exactly the correct direction, and made to lie in line with the proximal, and further, it can be rotated or deviated laterally by means of the transfixion apparatus.

It may appear at first sight a rather barbarous undertaking to thrust a metal pin right through a man's leg in order to manipulate his bone, but as a matter of fact it is a much less painful proceeding than the attachment of heavy weights to the limb by means of the skin, fascia, and ligaments, all of which structures are much more sensitive to traction and pressure than is the dense bone. If the transfixion is properly applied, and especially if the cutaneous perforations are so made (by drawing up the skin before piercing) that the skin is not dragged upon, there is astonishingly little pain.

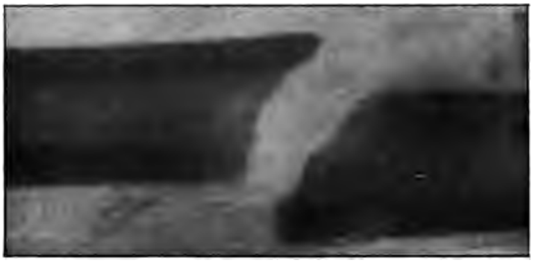

Fig. 32.—The same case as the last after one week's transfixion extension.

There is no other method of dealing with a severe displacement which leaves the limb so free from splints and bandages. From the very outset, therefore, it can be treated by massage with movement of the joints, and if there is an external wound, the dressing of this causes no displacement of the extending force.

The special indications for this method, then, are as follows:—

1. Great displacement of fragments by overlapping.
2. Old displacements.
3. Failure and inapplicability of other methods.
4. Open fractures.
5. Comminuted fractures.
6. Fractures near joints—especially the hip and the ankle.
7. As a preliminary to open operation in order to produce replacement.

The one great drawback to the method is that it involves the production of two open granulating wounds which must become septic sooner or later. When I used double transfixion rods in my experimental work (see Chap. V), I never found this factor cause any ill effects or produce any delay in healing. If the method is carefully applied, it is seldom any serious trouble arises in human patients, but it may lead to troublesome sinuses which take months to heal. Thus Riedle, in a recent paper on transfixion extension, refers to 40 fractures of the thigh and leg. Of these, 4 had delayed healing of the puncture wounds (four months to fifteen weeks), and 2 had serious infections, both the latter being cases in which other causes contributed to the bad result, one being an open fracture, while in the other the patient was a drunkard.

The only case in which I have seen serious sepsis was an open leg fracture in an alcoholic. In other cases there has either been some delay in healing of the wounds, or more often a re-opening of the puncture wounds by the discharge of a little pus with small fragments of bone. Such cases are rapidly cured by the application of a Bier's suction glass, and I do not think the occurrence of this complication is of sufficient importance to outweigh the other undoubted advantages of the method. Experience will no doubt enable us to minimize the dangers of the puncture wounds, and already I think we know enough to go far in this direction.

If transfixion pins be used in various situations, as, for instance, the upper and lower ends of the femur, the upper end of the tibia, or the malleoli, it is very soon found that some situations are much more liable to trouble than others. The two positions which are ideal are the lower end of the femur and the malleoli. Now at these points the bone lies directly under the skin and closely attached to it. There is very little tendency to dragging of the skin and subcutaneous tissues when traction is put upon a pin in these situations. And there is another advantage—namely, that as the bone lies just beneath the skin, the transfixion can be done through the merest puncture. I think that these facts give us an indication as to the best means of avoiding sepsis and irritation at the skin wounds. Two things are necessary. First, that the skin should fit snugly round the pin as a water-tight junction. Secondly, that there should be no tension on the skin round the pin. This may be ensured by pulling the skin towards the site of fracture before piercing it.

If this is not enough, so that when full extension is established the skin is dragged against the pin, it must be incised longitudinally through the tense area until it falls naturally. Then this incision is to be closely sewn up on the opposite side with several fine stitches.

The puncture wounds are painted with mastisol and dressed with fragments of gauze.

It is of first-rate importance to remove the transfixion pins within four weeks of their insertion. In the case of simple and comminuted fractures this gives ample time for the preliminary stages of consolidation to take place. With open and septic fractures, or those with much loss of substance, this limitation of the method must be most carefully borne in mind. It is far better to wait until active sepsis is at an end before applying the transfixion, than to be obliged to remove the pins before consolidation has taken place.

The Technique of the Ordinary Transfixion Extension.—This method having found its chief application in difficult fractures of the femur, it will be well to describe its application to that bone first, and then mention the other sites where it may be applied.

The transfixing pin should be 6 in. long by $\frac{3}{16}$ in. thick, made of hard steel which will spring without bending, and having a drill-point at one end and an attachment to a handle or drill-stock at the other.

The patient is anæsthetized by nitrous oxide, after the skin has been painted with iodine. A small longitudinal incision is made over the outer side of the external condyle, and the skin is drawn up a little, the pin inserted, and drilled through the bone until it pushes the skin before it on the other side. This is then cut. The wounds are dressed by mastisol, dry gauze, and wool, with a bandage, and the ends of the pin protected by screw-caps or by the caliper arrangement that Steinman uses for the attachment of the weight. Before the anæsthetic is discontinued, full traction should be made on the limb, thus for the time being overcoming painful muscle spasm. Then the patient is returned to bed and the limb supported in some kind of sling or sliding cradle which offers no resistance to the extending force (*Fig.* 33). The weight ought to be 20 to 25 lb. and the biggest weight is put on at once rather than added to day by day. The reason for this has been explained in the preceding chapter. In fractures in the upper third of the femur and those through its neck, full abduction with some flexion of the thigh should be adopted from the outset. At the end of a week a skiagram is taken, and if, as will probably be the case, the bone fragments have an appreciable interval between them, the weight is reduced by about one-fifth or one-quarter. After three to four weeks the transfixion pin is removed, this being quite easy and often not requiring an anæsthetic, and a simple plaster extension substituted. During this time the puncture wounds must be carefully attended to, and if they are unhealthy, it is better to treat them by daily application of Bier's suction-cups than to run any risk of their healing over a septic focus.

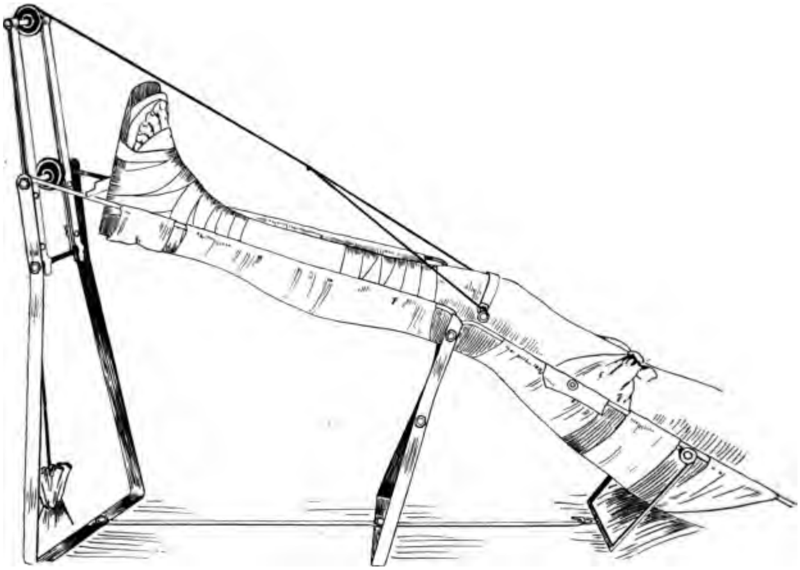

Fig. 33.—Extension by transfixion or by horseshoe screw clamp, the leg being supported on the author's wire cradle splint.

During the entire period of nail extension, light massage and movements of all the joints should be practised to the full extent every day.

Localities where Transfixion Extension can be applied.—Steinman gives the following situations: Lower end of femur, upper end of tibia, lower end of tibia, os calcis, lower end of humerus, olecranon, and lower end of radius.

But although it is quite easy to transfix the bones in any of these spots, only a few of them afford frequent indications for the application of the method, and some of them should in my opinion never be used.

The upper end of the tibia as the point of attachment of the weight is suggested for fractures into the knee-joint or so low in the femur as to make it impracticable to pierce the lower fragment. But, as I hold that all bad fractures into the knee-joint ought to be subject to open operation, I would not use it for this class of case except in septic gunshot fractures. The head of the tibia has the two great disadvantages for direct traction on the femur that it can only act through the knee ligaments, which will be stretched and weakened, and that it interferes with early exercise of the knee-joint.

The lower end of the tibia is quite useful for transfixion in cases of severe displacement in fractures of the leg; but instead of only perforating the tibia, it is better usually to go through both malleoli, because by this means all the muscles and vessels which lie between the tibia and fibula are avoided.

A point at least one inch above the tip of the internal malleolus is taken, and the pin made to emerge from the external malleolus. The drill guide which I describe in a later chapter is useful in accurately directing the transfixing pin.

The os calcis is, next to the lower end of the femur, the bone which has most frequently been made the point of application of the transfixion extension method. It is indicated in those complicated fractures in or above the ankle which are notoriously difficult to reduce or to get good functional results from. Only about 10 lb. to 15 lb. weight is required here, and usually it can be removed within a fortnight.

There is no situation where this method shows to greater advantage than when applied to the os calcis for complicated fracture-dislocations of the ankle. One has such complete command of the lower fragment, both in the reduction of the dislocation and the promotion of eversion, inversion, or rotation of the foot. Frequent *x*-ray pictures should be taken of the fracture until a perfectly good position has been attained. Then, after about two or three weeks, during which full massage and movement have been employed, a plaster case is fitted on to the foot, and cut into two halves the next day, after which massage is applied as before and the patient gets about on crutches, the plaster splint being re-applied daily for several weeks.

Of the application of the method to arm fractures I have but little experience, and few cases are reported in the literature.

The lower end of the humerus is badly adapted for transfixion. A line through the more prominent points of the epicondyles will always traverse the olecranon fossa, that is to say, it will penetrate the joint. Higher up, the transfixing pin must pass in close proximity to the musculospiral nerve on one side and the ulnar nerve on the other. If ever the method were used in this situation, it would only be for a very short time, and in cases of old fractures of the shaft of the humerus with much overlapping.

The use of the olecranon as a transfixion point has but little to recommend it, as it would greatly interfere with the exercise of the elbow-joint.

To transfix *the lower end of the radius* appears to me to be quite unjustifiable except as a means of exerting traction on a fragment during an operation. The transfixing pin must traverse the planes of both the flexor and extensor muscles, and in the front of the arm it also lies in the loose tissue containing the radial vessels and median nerve, and here any secondary sinus sepsis may have the most disastrous effects.

It is quite true that by transfixing the olecranon or the lower end of the radius we can act with precision in the replacement of certain fractures about the elbow and wrist-joints. But when such fractures have been replaced, there is little or no tendency for the displacement to return, and it is quite unnecessary to leave the transfixion pin for lasting extension. This will be discussed again in a later chapter.

MODIFIED FORM OF NAIL EXTENSION.

Direct Grasp of the Bone without Transfixion.—It has already been pointed out that the one great drawback to Steinman's direct nail extension is its involvement of sepsis, and that this is liable to take the form of deep sinuses from which particles of necrosed bone continue to be discharged for several months.

It is evident that if a potentially septic wound is necessary, the shallower this wound is the better, and on the other hand, the deeper the perforation of the bone, the longer will it be before septic particles are got rid of. With this idea in my mind, I have devised a simple apparatus for grasping the bone without perforating it at all. It consists of a horseshoe piece of steel of a size to take the limb (knee or ankle) easily in its concavity. Two screws are held by the limbs of the horseshoe, and are of such a length that they can be screwed into the bone from opposite sides. The points of these screws are of two different patterns. The one (*Fig.* 34) is simple, like a drill-point, and this is suitable for grasping the dense bone of the shaft of the femur or tibia; there is a shoulder above the point at such a distance that the drill cannot perforate beyond this thickness of bone. The other type of point (*Fig.* 35) is a loosely fitting triangular plate provided with three points. This adapts itself to the level of the surface of the bone, and takes hold of a larger area than the single drill-point. It is intended to grasp cancellous bone, such as the lower end of the femur or the calcaneum, where the delicate structure of such bone might be torn by a weight pulling on a single point.

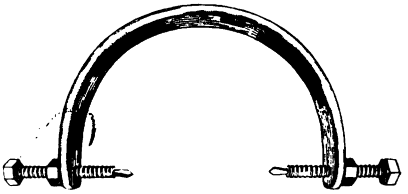

Fig. 34. — Author's horseshoe screw clamp for grasping a bone without transfixion. This type has simple drill points.

The appliance is adjusted to the limb through two small longitudinal incisions, the walls of which are held apart by small retractors whilst the screws are tightened up until they grasp the bone. When they are quite tight, the nuts on the screws are used to lock them in position.

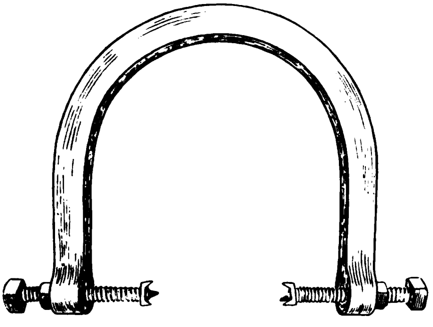

Fig. 35.—Author's horseshoe screw clamp for grasping a bone without transfixion. The points of the screws are triple, on a swivelled plate which adapts itself to the surface of the bone.

This screw clamp transfixion can be very readily applied to the lower end of the humerus. The points of the screws engage in the subcutaneous prominences of the epicondyles, into which they penetrate for a quarter of an inch. The extension is easily attached to the horseshoe band which connects the screws, either as a weight and cord running over a fixed pulley when the patient is in bed, or as a simple weight hung to the arm when he is up.

DOUBLE TRANSFIXION METHODS.

It will be seen in a later chapter that a large number of my most successful experiments have been done by means of a double transfixion apparatus which keeps the fragments at a correct distance but does not directly interfere with the seat of fracture. At the time these experiments were made, I did not know that a similar idea had been suggested by Lambret for clinical work, and I was so much impressed by the uniform excellence of my results in animals, that I began to use a similar device for various open and comminuted fractures in the human subject. However, to Lambret belongs the credit of having first used the double transfixion method. The principle is that of extension, but both fragments are transfixed, and this imparts to the extending force a more accurate action than that of a weight pulling against the body, and its employment is quite independent of the patient remaining in bed.

It is indicated in certain complicated types of fracture where operation would be difficult or dangerous. Open wounds, unhealthy skin, great comminution, and a tendency to the dislocation of the ankle, are the most usual of these conditions. Further, there are the cases of oblique fracture of both bones, with much overlapping, which refuse to be replaced by ordinary means, and in which the practitioner has not the facilities and experience necessary for a successful open operation.

The application of the transfixion apparatus is exceedingly simple ; it involves only a trivial risk of sepsis, and can be applied in a few minutes under gas anæsthesia.

I have tried various types of appliances for this double transfixion, and it may be well to narrate briefly the stages of thought and experience I have gone through before adopting my present model.

In the first place the apparatus consisted of a more or less rigid parallelogram, and this is the case also in Lambret's instrument. There were two great difficulties with this type. Inasmuch as the two transfixing-pins were parallel to one another, it was necessary to adjust the limb accurately before they were applied, and then to use some device by means of which they were driven into the two fragments of bone in a parallel direction; if this was not done, when the apparatus was fixed by the application of the side bars the transverse rods were forced to assume a parallel position, and the bones became displaced in consequence. Further, if any error was made during the application of the transfixing-pins, or any fault either of axial deviation or of rotation of the fragments was discovered afterwards by the *x* rays, such error could not be corrected without taking out and re-applying one of the pins.

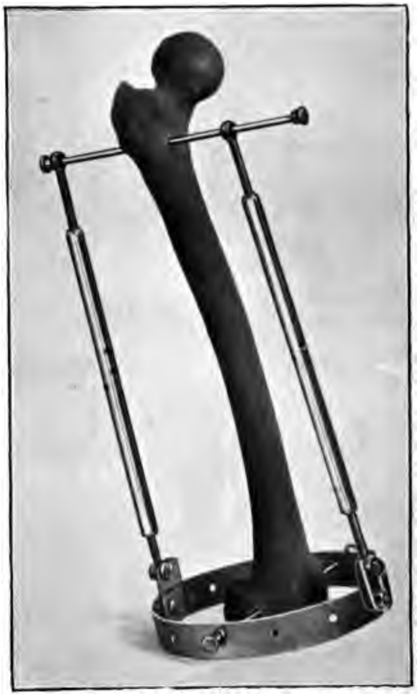

Fig. 36.—Double transfixion apparatus applied to femur.

I endeavoured to overcome these difficulties by the adoption of a kind of ball-and-socket joint at each of the four angles of the rectangle, capable of fixation by screws and nuts. But it was impossible to fix this so tightly that it would not work loose, and I never used it. It was in the search for a modification of the double transfixion method which would be applicable to the femur, that I solved the problem of working with transfixing-pins which were not parallel. And as this apparatus has now proved itself to be quite perfect, and very simple from a mechanical point of view, I think that it will supersede all other models. *Figs.* 36, 37, showing its application to the femur and tibia, demonstrate its general principles. One transfixing-pin is held at its two extremities by a flat steel band which encircles the limb. This band has twelve holes in it for the reception of the pin, so that any one of six different positions can be adopted; that is to say, the transfixing-pin can lie in any of six different diameters of the circle formed by the steel ring. To two opposite sides of this ring are attached the lateral extension-bars, each of which has the form of a tube screwing on to two bars with right and left-handed screw-threads. The side-bars are attached to the ring by means of quadrant joints which permit of movement through at least 20°. They can be absolutely fixed in any position by tightening a nut. The upper ends of the extension-bars slip over the ends of the upper transfixing-pins quite loosely, and a screw cap prevents them coming off. The loose fitting of the extension-bars to the transfixing-pins allows a considerable angulation of the pins to the bars.

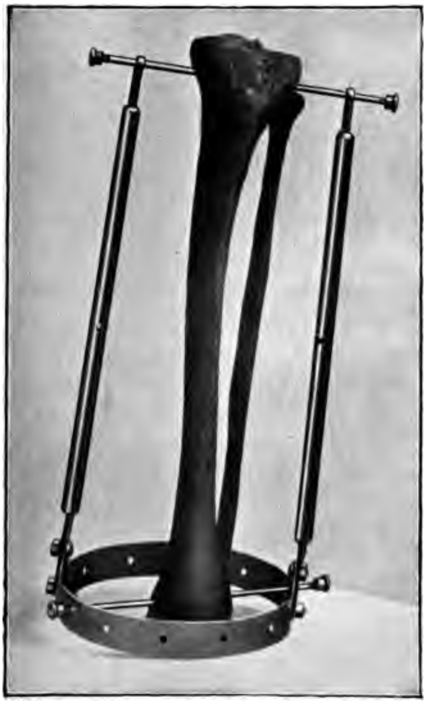

Fig. 37.—Double transfixion apparatus applied to tibia and fibula.

The general mechanical effects of this apparatus may be described as follows. Two ends of a long bone being each transfixed by a 6-in. pin, the steel ring bearing the extension-rods can be adjusted to these in any position, whether the pins are parallel or at right angles to one another. Rotation or angulation of the fragments can be adjusted at the time or subsequently, either by screwing one extension-bar more than the other or by tilting or rotating the ring, the quadrant joints being unlocked during this adjustment and then tightened up again.

So far I have only spoken of adjustment and fixation of the relative positions of the two transfixing-pins and the fragments which they pierce. But the chief function of the device is, of course, that it is a most powerful extension apparatus, which acts upon the broken bone without the intermediation of any other structure. Extension is obtained by rotating the screw tubes by means of a 'tommy' lever; by thrusting out the reversed-screw bars this is capable of producing an extending force of 200 lb. No force approaching this is usually required, and it would often be dangerous to exert it. But the transfixing-pins, made of hard spring-steel, bend slightly when subjected to 50 lb. tension. This is an indication that enough has been done, and the spring action of the pins will straighten them out in a few days, when a few extra turns are given to the extension-bars until the full extension has been produced. In a fracture which is recent (within two or three weeks), the full adjustment and extension can be done at once. In an older fracture it is much better to perform the work gradually, say within a week, rather than risk tearing the soft parts by full extension all at once.

This spring action of the transfixing-pins necessitates their being as long as six inches, and this ample length also ensures the apparatus being adaptable to any adult limb.

In order to prevent the limb slipping along the rod after tension has become reduced, it is well to fix a broad piece of webbing with a buckle round the limb and round the extension-bar from which there may be a natural tendency to recede. This strap is given a broad purchase on the limb by a moulded piece of poroplastic felt or aluminium splint.

This double transfixion apparatus was designed as an extension method, to be affixed to the broken bone whilst healing took place. But it at once becomes evident, when its power and adjustability are realized, that it is also the most perfect instrument for the adjustment of the displaced fragments of an old fracture as the first stage of any open operation. For this purpose it has the advantages of being quite away from the field of the operation, and of holding the bones in position whilst the permanent screws or bolts are being fixed in place.

Application to the Humerus.—The humerus lends itself to other extension methods so well (the Y-spring splint or the screw clamp) that it will very rarely need this apparatus. It might, however, be useful for an old case with much overlapping, or as a preliminary to open operation.

The upper end of the humerus is transfixed from before backwards. A point is taken midway between the inner and outer border of the arm, and on a level just below the middle of the deltoid. The hand is held pointing directly forwards with the elbow bent. The line midway between the outer and inner borders of the arm marks the division between the deltoid and the great pectoral muscles. In this interval lies the cephalic vein. It is therefore best to make an incision about an inch long, in order to see this vessel and hook it aside. The muscles are then retracted and a small space cleared down to the bone, which is transfixed to the outer side of the biceps tendon. The pin emerges between the deltoid and the triceps behind, and if it is kept just below the middle of the length of the deltoid, the circumflex nerve will be avoided.

The lower end of the humerus is transfixed from side to side, one and a half inches above the epicondyles, in front of the internal epicondylar ridge and behind the outer. In this way both the ulnar and musculospiral-nerves will be avoided.

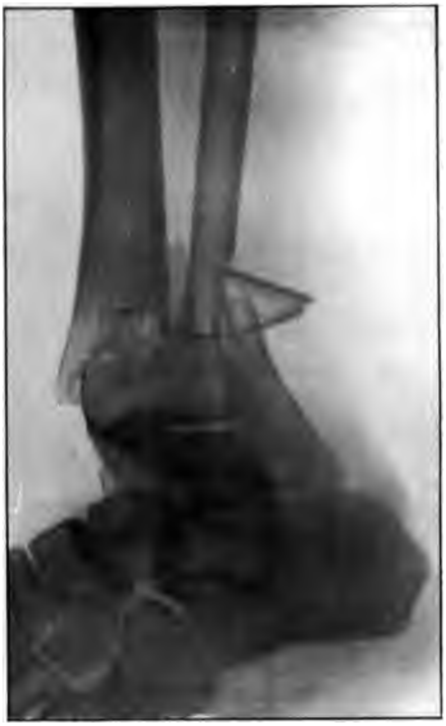

Fig. 38.—A complicated supramalleolar fracture before treatment.

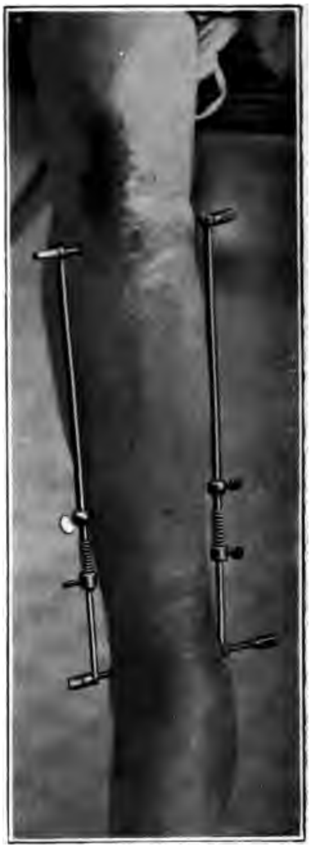

Fig. 39.—The leg shown in *Figs.* 38 and 40, with the double transfixion apparatus (early pattern) applied.

The metal hoop which surrounds the lower end of the arm is shaped so as to be above the forearm when the latter is flexed.

Application to the Femur.—The upper transfixing-pin is applied in an anteroposterior direction, but rather from within outwards, so that the posterior end emerges on the outer aspect of the thigh behind the great trochanter. The anterior point for transfixion lies vertically below the anterior superior iliac spine and on the same level as the lower border of the symphysis pubis. The lower pin is driven transversely across through the condyles of the femur.

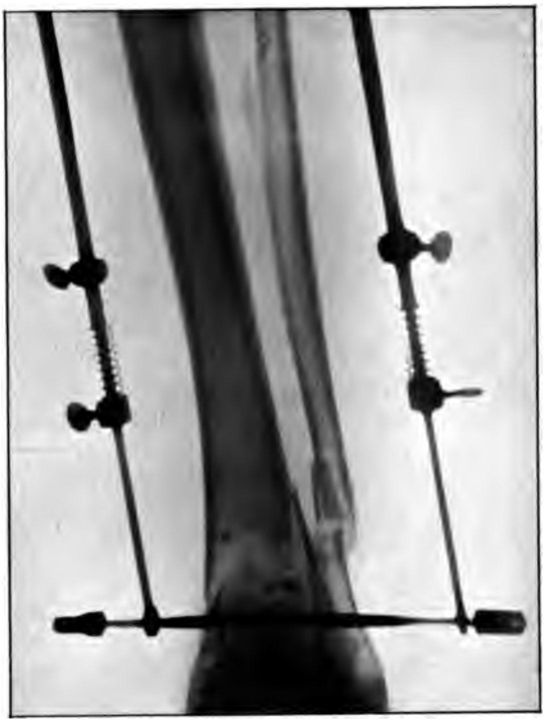

Fig. 40.—The fracture shown in *Fig.* 38 under treatment by the earlier form of double transfixion apparatus.

Application to the Tibia and Fibula (*Figs.* 38, 39, 40, 41, 42). —The upper pin is passed transversely just below the tuberosities of the tibia, rather above the level of the tubercle. This will

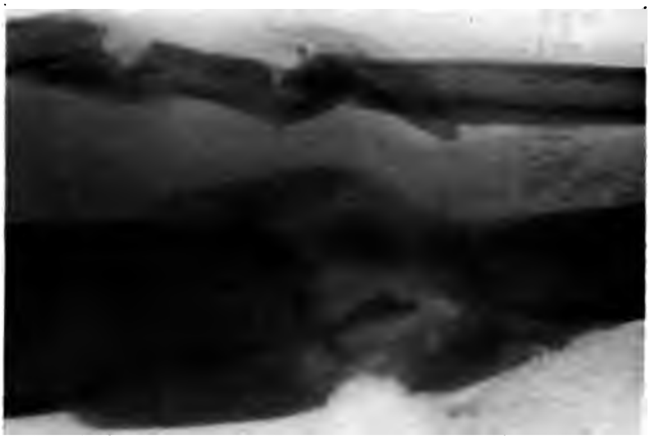

Fig. 42.—The fracture shown in *Fig.* 41 after treatment by the double transfixion apparatus.

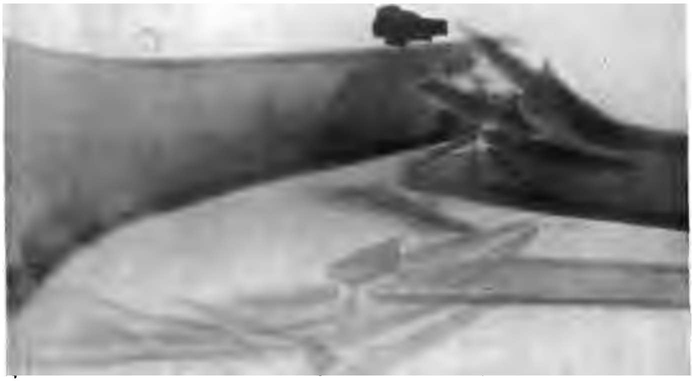

Fig. 41.—Complicated gunshot fracture of tibia and fibula before treatment.

avoid the danger of injuring the knee-joint or the vessels and nerves. The lower pin is best passed through both malleoli, in which case its direction will be transverse, with the outer end lying behind the inner. It is important that it should be at least one inch higher than the tip of the internal malleolus, otherwise the ankle-joint may be entered.

If the fracture is just above the ankle-joint, the lower pin must transfix the os calcis, and this gives a very efficient point of application.

CHAPTER V

OPERATIVE TREATMENT: EXPERIMENTAL OBSERVATIONS *

THE most essentially modern of all methods of the treatment of fractures is by open operation.

When it was suggested some twenty years ago that closed fractures should deliberately be made open, the suggestion was received with much hostile criticism.

But the increasing use of the *x* rays, with the demonstration afforded by them of the very inexact reduction obtained by bloodless methods, together with the great improvements in operative technique, have changed the attitude of surgeons in this matter. Indeed it is the advent of the proposal for operating upon the majority of closed fractures which present much displacement which has been the greatest stimulus to all work on the treatment of these injuries. On the one hand there have been extreme advocates of operative measures, such as Lane and Lambotte, who have devoted themselves to extending their technique to deal with all possible cases, and who would regard open operation as the routine treatment for broken bones. On the other hand, the advocates of the purely conservative method of splint treatment have been forced to take far more pains in the application of their appliances, in order to justify their refusal to adopt the new suggestions.

There has arisen also a more exact application of the principles both of 'massage' with movement, and of extension, forms of treatment which have done so much towards removing from bloodless methods the reproach that these usually result in faulty position and bad function in broken limbs. It is not that either the massage or the extension methods have arisen from the operative—as a matter of fact they are both of much earlier origin; but the proposal that open operations should be the routine method for treating fractures has forced surgeons who must admit the defects of the old treatment, but who are not prepared to adopt the new, to find some middle course and to try 'massage' or 'extension.'

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* This chapter, with slight changes, is taken from the author's article dealing with the same subject in the *British Journal of Surgery*, Jan., 1914.

It is common knowledge that the results of the operative treatment of fractures leaves a great deal to be desired. If a broken bone could be sutured with the same ease and certainty of a quick union as is the case in a 'rupture' of the abdominal wall, then indeed open operation would have become the routine method for all fractures as it is for all hernias. But the operative treatment of fractures is difficult; it requires special instruments and special experience; it often gives results which functionally are no better than the average obtained by the splint; and it sometimes leads to disaster.

The very great preponderance of surgical opinion is now so convinced of the following two propositions that it is unnecessary to spend time in arguing the question of their truth.

1. That a certain number of closed fractures require open operation.
2. That a certain number of closed fractures give as perfect an anatomical and functional result by non-operative as by operative methods, and that in these cases, therefore, no operation is required.

The two questions, on the other hand, which are all important are :—

1. How are we to select for operation those fracture cases which will give a bad result by the old method and a good result by the new ?
2. What operative technique ought to be adopted in each case that is operated on, in order to give perfect functional results ?

It is exceedingly difficult to answer these questions with any approach to accuracy from clinical evidence alone. The circumstances of clinical observations vary so enormously, that comparison of the results of different methods of treatment is almost impossible. Some of the more important of these varying factors are : the age and health of the patient ; the site and anatomical condition of the fracture ; the length of time that has elapsed before treatment was undertaken ; the period between the termination of the treatment and the recording of the result ; the skill and attitude of mind of the surgeon in the method employed. It is only by experiment that these variables can be replaced by constants, and a true estimate made of the factors which underlie success or failure of operative methods.

My primary object in taking up this research was to determine the comparative merits of the different methods of operative fixation of fractured bone fragments, as judged by the organic union produced by them. In particular, I wished to ascertain whether the rapidity and firmness of repair were the better promoted by intramedullary pegs or by external plates and screws. But one inquiry led on to another, and the appearance of Sir William Macewen's epoch-making work upon the growth of bone gave me a fresh stimulus to examine the source and method of formation of callus.

REVIEW OF THE EXPERIMENTAL STUDY OF OSTEOGENESIS.

Before describing my own work, a few words are necessary in relation to similar work done by others. In the broad meaning of the term, the experimental study of bone injuries and bone growth in the lower animals is dealt with in a vast body of literature which it is difficult even to catalogue and almost impossible to epitomize. The three burning questions of the origin of callus, the role of the periosteum, and the viability of bone-grafts, have dominated this literature to such an extent that scarcely any other topic is mentioned. In 1692, Havers, whose name has ever since been identified with the vascular canals of the bone, described the periosteum as simply a connective-tissue limiting and vascularizing membrane ; but his work, apart from mere speculation, was purely anatomical and microscopical. A less remembered observer, Antoine de Heyde, in 1684, published the first experimental observations on fractures, having worked with frogs, and having come to the conclusion that callus was formed by calcification of the blood extravasated round the broken bone ends. It was, however, in the middle of the eighteenth century (1739–1743) that the first systematic work on this subject was carried out by Duhamel, who was the originator of the modern generally accepted theory of the function of the periosteum. In his view the periosteum became thickened and succulent round a fracture, and by pushing this new tissue in amongst the fragments, it formed the callus. He it was who founded the term "cambium layer" of the periosteum, which is now in everyday use in German literature. Eighteen years later, Troja produced experimental necrosis, and described the new bone formation between the dead bone and the periosteum. A century after Duhamel, after many less remembered works and discussions on the subject had appeared, came the great work of Ollier (1867), which remains to-day as the foundation of all our exact knowledge of bone growth. Ollier's work was so thorough and careful, that his conclusions have attained an almost unassailable position. He proved the regeneration of bone from periosteum in every possible way, and ever since his day the periosteum has been regarded as the most important vital tissue of the bone. Nearly fifty years have elapsed since Ollier's treatise, and during this period practically the whole of modern surgery has arisen. Very many works have been written dealing with fractures experimentally produced, but these have chiefly concerned themselves with the structure and origin of callus. More recently, the practical question of filling bone defects by grafts of dead or living bone obtained from various sources has absorbed the attention of workers, who have sought to examine experimentally this method of bone re-construction. The most notable contributions to this part of the subject have been those of Barth (1893) and Axhausen (1898). The former showed that large living bone masses, when transplanted, lost their vitality, and acted in the same way as a piece of dead bone, i.e., as a mere splint or scaffolding on which new bone is laid down. The latter proved that certain areas of transplanted living bone retained their vitality, and acted as centres of new bone formation. Every practical worker on the subject, moreover, has endorsed the opinion that a living bone of the same species gives much quicker, stronger, and more certain results than dead bone or than that taken from another species.

It was in 1911 that Macewen produced a simple little work entitled " The Growth of Bone," in which he showed, by a few most convincing experiments, that bone growth can and does take place quite independently of the periosteum, and that the periosteum is in no way essential for bone growth. As a deduction from these observations, the author would once more revert to the view of the periosteum taken by Clopton Havers in the middle of the seventeenth century, viz., that it is chiefly a vascular limiting membrane.

But in all the literature of this subject I have been unable to find any detailed account of experimental observations on the operative treatment of fractures. There have been papers by Rossi, Roncali, Potârchâ, whose titles suggest that they may have a bearing on this aspect of the question, but unfortunately they are not accessible in this country. Bum, Forlini, Bergel, Pochammer and Schmieden have made experimental observations on the influence of passive congestion or the application of fibrin or blood-clot in the hastening of fracture repair. All the other papers deal with the formation of callus, or the rôle of the periosteum or medulla in experimental fractures. At the end of this chapter I have given references to all these papers, classified according to their subject matter.

A GENERAL DESCRIPTION OF THE METHODS EMPLOYED AND THE MATERIAL USED.

I began with the idea of using dogs, cats, and rabbits as subjects of my experiments, but was very soon led to modify this plan. The use of dogs is not only expensive, but it involves many unnecessary difficulties when a number of animals have to be kept under observation at the same time; and up to the present I have not employed any of these animals. Nineteen rabbits were used, but the frailty of their bones made them difficult to deal with, and splintering of the shaft is liable to take place. Further, the fact that in the leg bones the fibula of the rabbit is not a separate bone, but only a slender ossicle which is fused with the tibia at its lower end, makes it difficult to fracture the tibia without at the same time breaking the fibula.

The tibia of the cat is in every way most suitable for an extended series of experiments. It is stout and strong, it has a medullary cavity $\frac{1}{8}$ in. to $\frac{5}{32}$ in. in diameter, and can be drilled in various directions without breaking. The fibula, moreover, is a separate bone, which, whilst allowing free manipulation of the tibia, nevertheless serves as a splint in helping to maintain the tibial fragments in position. Of my 100 experiments, 81 have been on cats and 19 on rabbits; 65 on the tibia and 35 on the femur.

As regards the operative technique, it may be well to describe here the general plan which has been followed, reserving the description of special methods until later.

The animals were anæsthetized by a laboratory attendant with open ether, and then tied to a warm table by the four paws. The thigh or leg was shaved after washing with ethereal soap, bathed with spirit and ether, and after drying, painted with 10 per cent iodine solution. A towel with a median slit was placed over the animal, and the edges of the slit secured to the area of operation by a few stitches. No lotions were used, the swabs were all dry, and the general technique was exactly as in an ordinary surgical operation, including, of course, the use of dry-sterilized gowns and gloves. The majority of the actual operations were carried out single-handed, though occasionally a retractor was held by an assistant through the towel. It was very seldom necessary to ligature a vessel. Drainage of the wound was never done, the fascia and skin being closed separately by fine continuous catgut stitches. The wound was dressed by a small fragment of gauze smeared with 10 per cent iodine in collodion. About a week after the operation this gauze came away, and the wound required no further attention. No attempt was made to fix the limb in any way after the operation, the animal being simply placed in a roomy cage upon clean hay.

The conditions of my licence required me in every case to divide the bone by a saw or forceps through an incision in the soft parts. This was done in most cases by a fine fret-saw, making an incision as nearly as possible at 45° to the long axis of the bone.

Fixation by Short Plates and Screws.—In modern surgical practice, the method of fixing fractures which has become most popular is that of "plating." A short steel plate is used, and this is screwed on to the outside of the bone by short screws which hold the dense bone, but do not penetrate the medullary cavity. I endeavoured to carry out this principle in animals, but without any success.

The plates used were $\frac{3}{4}$ in. long, $\frac{1}{8}$ in. wide, with two holes at either end. The screws were $\frac{3}{16}$ in. long. In order to ensure a good position of the bone, the holes were drilled, then the saw-cut made part way through the bone, the plates were screwed into position, and the division of the bone was completed. In this way a firm fixation was always made in a perfectly good position. But in all nine experiments—two cats (tibias), two rabbits (tibias), five rabbits (femurs),—the bone ends became disunited within the first week, with more or less angulation and deformity. This was due in every case to the screws coming out. Usually both screws came out from one fragment and the plate remained firmly fixed to the other; but sometimes all the screws were out, and the plate was loose among the muscles.

Examination of the bones from these cases shows that the screw-holes become enlarged, so that whereas the screws hold tightly at the time, later the same-sized screw will drop loosely into the hole. The whole muscular force of the leg acts upon the grip between the screw-thread and the bone, and the latter quickly gives way by a process of absorption.

A second undesirable feature of this series of experiments was the tendency to sepsis, with occasional extrusion of the plate. In three cases there was a septic discharge from the wound, and in a fourth, though the wound was healed, there was periostitis, and a large abscess cavity among the muscles. This marked tendency to sepsis, as compared with other methods, is due to the combination of great irritation caused by free movement of the displaced fragments, and the presence of a foreign body. That it is not due to faulty technique is shown by the fact that in other methods where the same procedure was observed there was very little sepsis. That it is not due simply to the presence of foreign bodies is evident by the fact that, in the next series, where very much larger plates and pins were used, it did not occur once.

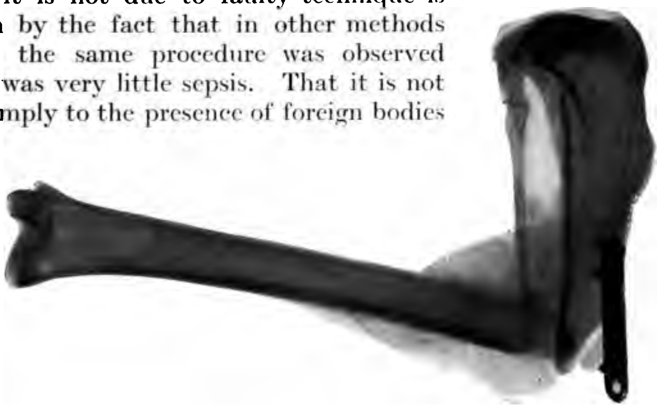


Fig. 43.—Skiagram of rabbit's tibia, 21 days after plating. The screws have come out of the lower fragment. The plate protruded from the wound.

Thus two facts are demonstrated clearly: (1) That short plates and screws, in the absence of external splint fixation, rapidly become loose; (2) That when the fixing agents are once loose amidst the displaced fragments, sepsis is very likely to be set up.

Of course the circumstances of these experiments are not the same as in human surgery. The size of the bones is such that very small screws have to be used. The co-operation of the human patient, with the use of external splints, will make the loosening of the plate much less likely. But if the application of splints is necessary after the plating of a fracture, the method be liable to some of those very evils of the splint treatment h the operation is intended to avoid; that is to say, the scles and joints will suffer from long immobilization. More-er, in spite of the use of splints, it will often be found in human rgery that the plates and screws do become loosened. This nay be demonstrated by the *x* rays, and is proved by those cases where, weeks after the healing of the wound, a sinus is formed leading down to loose plates and screws.

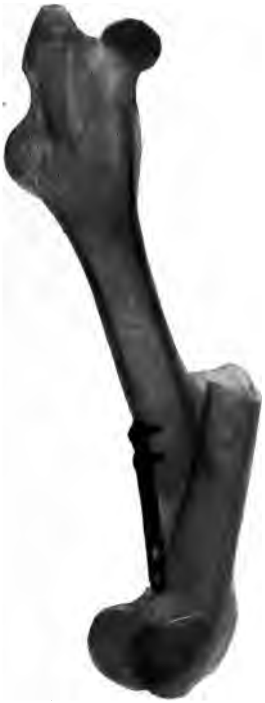


Fig. 44.—Rabbit's femur (No. 26), 21 days after plating. The screws have come out from the lower end. Mal-union.

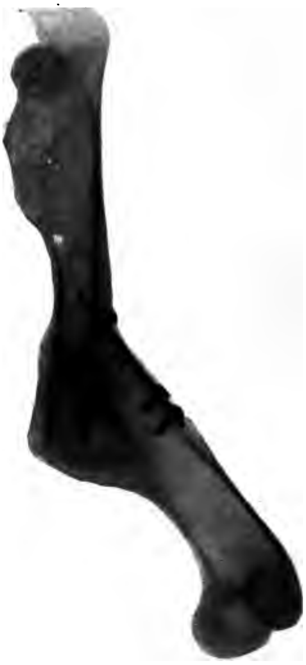


Fig. 45.—Rabbit's femur (No. 28), 31 days after plating. The screws have come out from the upper fragment. Note the quantity and density of the callus.

The general pathological features of this series may best be described by a few skiagrams and drawings.

***Fig.* 43** is a skiagram from a rabbit's tibia (No. 23), twenty-one days after operation. The plate remains firmly fixed by the upper screws. There is marked angular deformity.

***Fig.* 44** is a skiagram of a rabbit's femur (No. 26), also twenty-one days after operation. There is marked overlapping of the fragments, and both the screws have come out from the lower fragment and are lying loose in the soft tissues. Healing was aseptic.

Fig. 45 is a rabbit's femur (No. 28), thirty-one days after operation. The screws have become displaced from the upper fragment, and the bone is united with marked angular deformity by callus, which is exceptionally dense for this period. Healing was aseptic.

Fig. 46 is from the tibia of a cat (No. 32), nineteen days after operation. The screws have come out from the upper fragment and have been discharged from the wound, which has become septic.

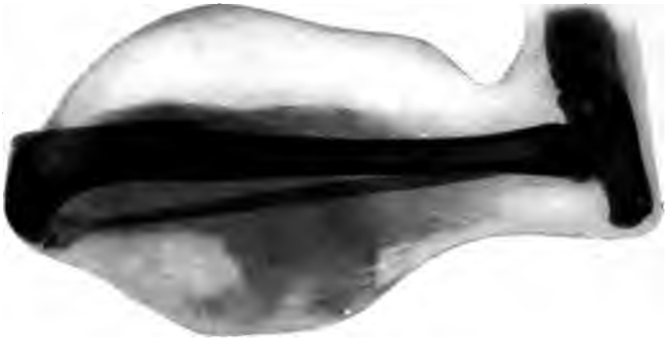


Fig. 46.—Cat's tibia, 19 days after plating (No. 32). Screws have come out from upper fragment, and have been discharged through the wound.

It may be noted that in these four examples both the tibial cases became septic. This is not due to any difference of technique, and in fact the tibia is much easier to plate than the femur. I believe that the sepsis is the result, and not the cause, of the loosening of the screws. It is evident from this series that the screws do rapidly become loose in all cases under the given conditions. Directly a little movement is possible between the screw and the bone, and between the bone ends, there is a great outpouring of tissue secretion, both fluid and cellular. If the source of irritation and the fluid collection lie just under the skin, the wound will probably be opened by the mere tension of the fluid, or by the direct pressure of the plates and screws (see *Fig.* 43). Once the wound is open for the fluid discharge, septic infection of the whole area is inevitable. This point is of great importance, and I shall refer to it again later.

***Fig.* 47** is a drawing of a rabbit's femur (No. 25), forty-two days after operation, the wound of which had healed without sepsis. The plate fixation had given way very soon after the operation. It shows the great callus excess usually produced

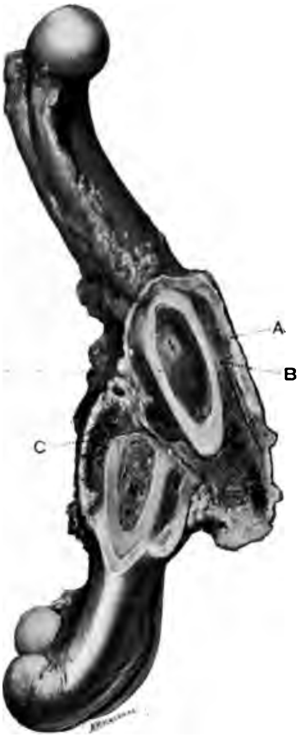


Fig. 47.—Rabbit's femur (No. 25), 42 days after plating. Mal-union with great angulation. A section has been made through the line of junction to show the structure of the callus.

A, Peripheral cartilaginous callus.
B, Ossified callus next to the bone.
C, Line of fracture where callus is still cartilaginous.

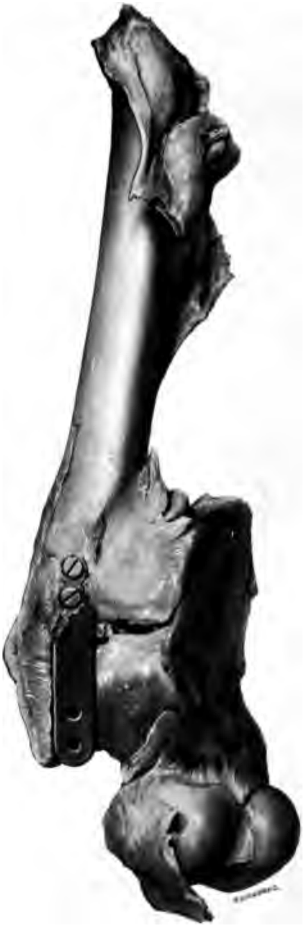


Fig. 48.—Rabbit's femur (No. 26), 21 days after plating. Screws have come out from the lower fragment. Mal-union with lateral displacement.

in conditions in which the raw bone ends have much mobility—that is to say, conditions of mechanical irritation. Each broken fragment is covered in by an exuberant callus mass, which has ossified next to the bone, but peripherally remains cartilaginous. The line of fracture is still distinct.

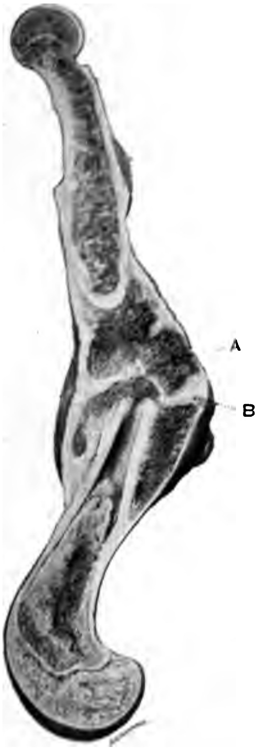


Fig. 49.—Rabbit's femur (No. 28), 31 days after plating, cut down the centre to show union.

A, Ossified callus. B, Callus which is still cartilaginous at the line of fracture.

Fig. 48 is a drawing from the same case as *Fig.* 44, i.e., a rabbit's femur twenty-one days after operation (No. 26). It shows, as in the last specimen, the lateral union of the fragments by the callus excess, the plate still being firmly screwed to the upper portion, but the screws having come out from the lower.

Fig. 49 is a drawing from the same case as *Fig.* 45, i.e., a rabbit's femur thirty-one days after operation (No. 28). It presents the same callus excess as the last two cases, and the same arrangement of ossified and cartilaginous areas, the cartilage remaining chiefly at the periphery and at the line of fracture.

The next two specimens show the formation of a false joint. It is most difficult to say exactly what circumstance determines in any given case whether a mal-united fracture will heal by callus excess, or whether non-union with a false joint will occur. Pathologically it clearly depends on whether much active callus is formed, or whether there is merely fibrous union, allowing free play of the bone ends; but the conditions which determine whether much or little callus is laid down may be various. Three such circumstances are, the degree of mobility, the interposition of soft parts, and the tendency of the bone to callus formation as influenced by blood-supply or the age of the bone. In the cases now under consideration, the only constant difference between those where there was mal-union with callus excess, and those where a false joint occurred, was the age of the animals, as judged by the junction of the epiphyses. The young bones, in which the epiphyses have not yet joined, all formed callus excess; but the older ones, whose natural growth had ceased, formed false joints.

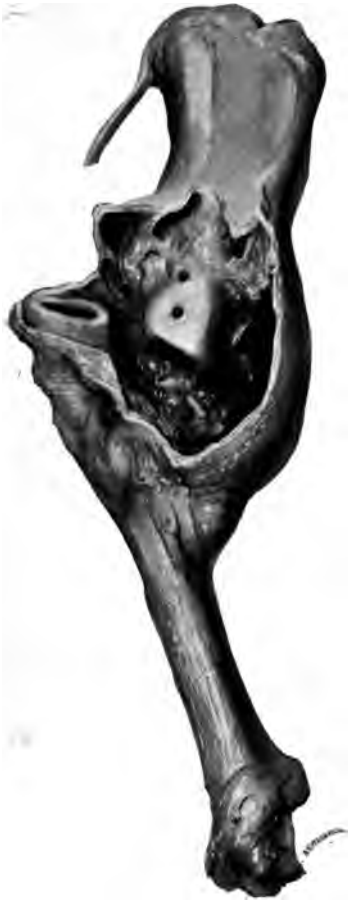


Fig. 50.—Rabbit's tibia (No. 24), 33 days after plating. All the screws have come out. An early stage in the formation of a false joint is present. The ends of the bone are becoming rounded off. The screw-holes are enlarged and their edges rounded.

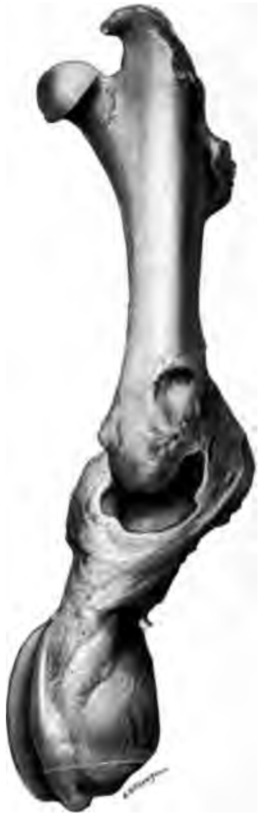


Fig. 51.—Rabbit's femur (No. 27), 38 days after plating. There is a perfect false joint, of which the upper fragment forms the ball and the lower the socket.

Fig. 50 is a rabbit's tibia (No. 24), thirty-three days after the operation. Healing was aseptic. The bone ends are widely separated, and lie in a large cavity which was partly filled with fluid and partly with fibrin. The soft tissues are matted together to form a strong fibrous capsule. Both bone ends are bare and their edges rounded, whilst the screw-holes are enlarged and smoothed away, the plate and all four screws lying loose in the cavity of the joint. The *x* rays show that both epiphyses have fused with the shaft.

Fig. 51 is from a rabbit's femur (No. 27), thirty-eight days after operation. Healing had been aseptic. A very perfect new joint is seen between the fragments. The lower end of the upper portion of bone is smooth, rounded, and covered by fibro-cartilage, and it rests in a socket on the front and outer side of the lower fragment, this socket being made up by the saucer-like edge of callus to which the fibrous capsule of the joint is attached. It will be noted that here there is no callus excess, and the epiphyses are fused to the shaft.

Long Plates and Perforating Pins.—It was quite evident that the short plates held in place by short screws which only penetrated one side of the dense bone were (apart from splints) quite unable to retain bones in position. I therefore tried some much longer and thicker plates, and fixed these in position by pins, technically known as "cotter" or "split" pins, which perforated the entire thickness of the broken shaft. In one case the plate used was 2 in. long and $\frac{1}{16}$ in. thick, but in the other it was only 1½ in. long and $\frac{1}{32}$ in. thick. They were not flat, but in cross section formed a quarter of a circle $\frac{5}{16}$ in. in diameter. The pins were $\frac{1}{16}$ in. thick, and after being thrust through the plate and the bone the split ends were turned back so as to keep the pin and plate in position.

It was only necessary to do a few of these experiments, all of which were on tibias of cats, because the method was uniformly successful. In none was there any sepsis, the wound healed by first intention, and the animals used the leg freely during and after the second week. The periods of observation varied from four to six weeks. In three of these experiments the healing of the bone was quite ideal. The callus was of a minimum amount, and true bony union was evident from the fourth week onwards.

Figs. 52 and 53 show four of these specimens, by the *x* rays, and after dissection.

(*a*) is No. 54, twenty-eight days after operation. The seat of union is already firm bone, and the medullary cavity is filled with dense internal callus. Of external callus there is only a thin layer, which partly covers in the plate.

(*b*) is from No. 48, thirty-four days after operation. This was the specimen in which the longer (2 in.) plate was used. Here, although with a longer plate immobility must have been more assured than in the others, there is some callus excess, the line of bone union is not complete, and there is a wide area of cartilage in the callus mass.

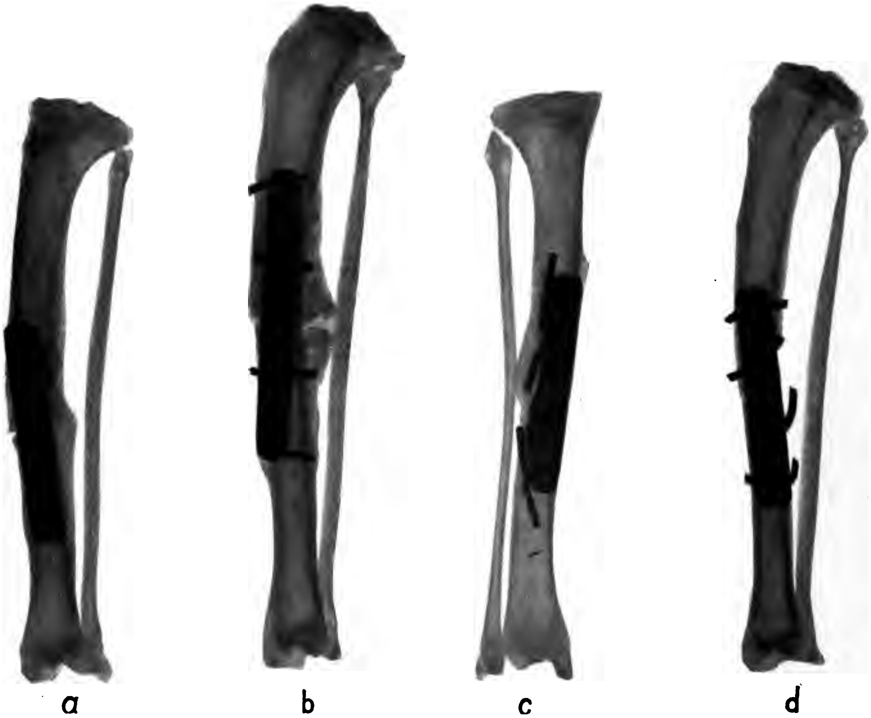


Fig. 52.—Skiagram of Four Cats' Tibias United by Long Plates and Perforating Pins.

(*a*). No. 54, 28 days after operation. (*b*). No. 48, 34 days after operation. (*c*). No. 53, 42 days after operation. (*d*). No. 52, 42 days after operation.

(*c*) is No. 53, forty-two days after operation, and in ***Fig.* 53** the specimen is shown cut down the centre. Complete and perfect union has taken place, with very little external callus. Internal callus is firm, and the dense bone of the shaft is thickened on its medullary aspect, above and below the fracture.

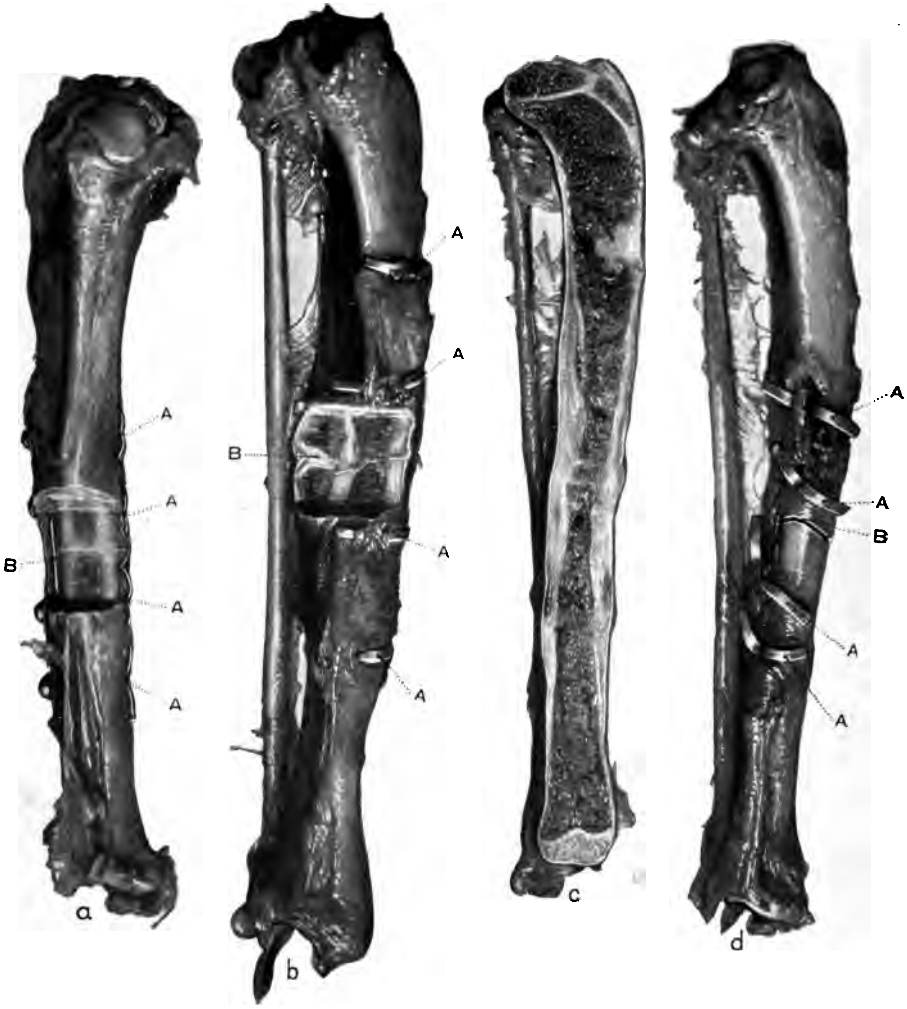


Fig. 53.—FOUR CATS' TIBIAS UNITED BY LONG PLATES AND SPLIT PINS.
(*The same as Fig.* 52.)

(*a*). No. 54, 28 days after operation. A piece of bone has been cut out to show the union. A, Ends of split pins turned over. B, Edge of the plate.

(*b*). No. 48, 34 days after operation, a piece having been cut out to show union. A, Ends of split pins. B, Wedge-shaped cartilage in the callus at the line of fracture.

(*c*). No. 53, 42 days after operation, cut down the centre, after removal of the plate and pins. There is perfect union. No external callus, visible as such ; a short plug of internal callus, and a notable thickening of the dense bone of the shaft some distance above and below the fracture.

(*d*). No. 52, 42 days after operation. No callus, no union. A, Ends of the pins. B, The line of fracture, the edges of which are quite sharp, cut.

The plate has been removed, and there is perfect solid continuity of the two halves of the bone.

(*d*) is from No. 52, forty-two days after operation, and it affords a rather startling contrast to the other members of this series. Although, as regards function, this animal had been just as well as the others, the wound having healed by first intention and the limb being used freely, yet, nevertheless, the specimen shows a complete absence of callus or any repair, the ends of the bone having undergone an aseptic necrosis up to the nearest pin on each side. The animal was young, and the epiphyses were still separate from the shaft. The only circumstance that appears to be different in the conditions of this operation from those in the three other similar experiments, is the fact that the ends of the pins have been left rather long and have been turned transversely, so as partly to surround the bone. This is shown best in the skiagram (*Fig.* 52 *d*). The effect must have been to keep the periosteum and soft parts at a distance from the bone, thus hindering the vascularization of the cut ends.

The importance of this exceptional result is great, in view of the fact that in human surgery many observations have been made that the operative treatment of fractures is accompanied by much-delayed repair of bone. It has been customary to attribute this to an immobility which has deprived the bone of the usual stimulus of friction and movement. The above experimental evidence does not support this, because it has been shown that in all the other cases rapid and perfect bone union has occurred when the fragments have been absolutely fixed.

It has been assumed that bone tissue must either be living, with full vitality and reproductive activity, or else necrosed and cast off as a sequestrum. But it seems certain from many observations that bone may be in an intermediate state, in which circulation and tissue change come to a standstill for the time being, to be re-activated at a later date. Such is the condition of things when a large piece of bone is transplanted from one situation to another. The greater number of its cells die, but later on it is penetrated by other bone-cells and takes on the appearance of new growth. There has been much discussion as to the nature of the bone in this intermediate state. Some say frankly that the bone is dead; but this seems unreasonable in view of the fact that within a short time it is certainly alive and growing. Others say that it merely forms the scaffolding tissue into which cells penetrate and build up new bone. But whatever may be its nature in this latent period, it would seem that it is this stage through which the ends of the broken bones pass, in these exceptional cases, when treated by operative methods. Aseptic necrosis, or suspended vitality, of an injured bone may be caused by any manipulation, and it usually affects the ends of the broken fragments, being determined most probably by an interference with the blood-supply. It will naturally cause a very great delay in the union of a fracture.

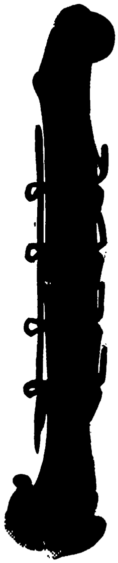


Fig. 54.—Skiagram of a cat's femur (No. 92), 53 days after fixation by double plates and split pins.

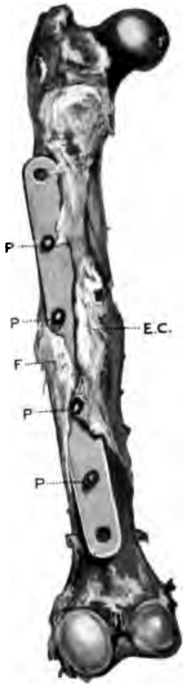


Fig. 55.—Drawing of the same femur as *Fig.* 54. P, Heads of pins. F, Site of fracture. E. C, External callus growing over plate.

If the method of operative fixation is one which lasts but a short time, e.g., by plates and screws, the fracture will become displaced long before union occurs. On the other hand, if the fixation is of a more permanent character, the delay in the vital action of the bone tissue is of no great matter, because the limb can be used for its full functional activity whilst the delayed repair is going on. One fact, however, stands out clearly in comparing these two methods of plate fixation ; the mere size of the plate has nothing at all to do with its liability to set up inflammation, which may cause its extrusion. A large plate firmly fixed will remain in place indefinitely, whilst a small plate which becomes loose will set up irritation which leads to its being thrown off. Firmness of fixture is the dominant factor which determines most often whether a plate will remain in position or become loose.

Nickel-plated steel has no irritating effect upon the tissues ; but if a plate is attached to a bone in such a way that slight but constantly recurring movement is permitted, it will cause mechanical irritation, bone absorption, fluid collection, sinus formation, and finally sepsis. It will be a mere chance in the latter case whether the plates have done any good at all. If they have held the bone in position until union has occurred, their ultimate removal may be a matter of comparative indifference ; but if, as is so often the case, they give way before bone repair has taken place, they are worse than useless, because they hinder repair and often bring about sepsis.

An experiment (No. 92), made at a much later date, may be placed with the foregoing. It is illustrated in ***Figs.* 54** and **55**. A cat's femur was fixed between two flat plates, and the latter were joined together by means of four split pins, which perforated the whole thickness of the bone. The skiagram gives a good representation of the arrangement. Healing was good and function perfect, and the animal was killed fifty-three days later. The drawing (***Fig.*** 55) shows how the external callus is growing over and enclosing the plates.

Outside Metal Collars. (*Table III.*, p. 162.)—In this group are included seven experiments, all of them being on the cat's tibia. In four, the material used was aluminium plate ; in one, steel plate ; in one, magnesium plate ; in one, aluminium-bronze wire. When metal plates were used, they were cut out of thin sheet, wrapped round the bone fragments, and then secured by wire. As far as possible the periosteum was raised from the bone, and the plate secured between the two structures. In three of the experiments the fixation was insecure, and one end of the bone became dislodged from the embrace of the metal collar. There are therefore only four for consideration. In all of these the same course of events is seen, although in different stages.

Mechanically, the collar is a good method of fixation, and the position and function of the limb appear to be quite normal ;

but the process of repair is delayed and weak even after a long period. At first sight it seems as though the ends of the bone grasped by the collar had undergone necrosis, but closer examination shows that this is not so.

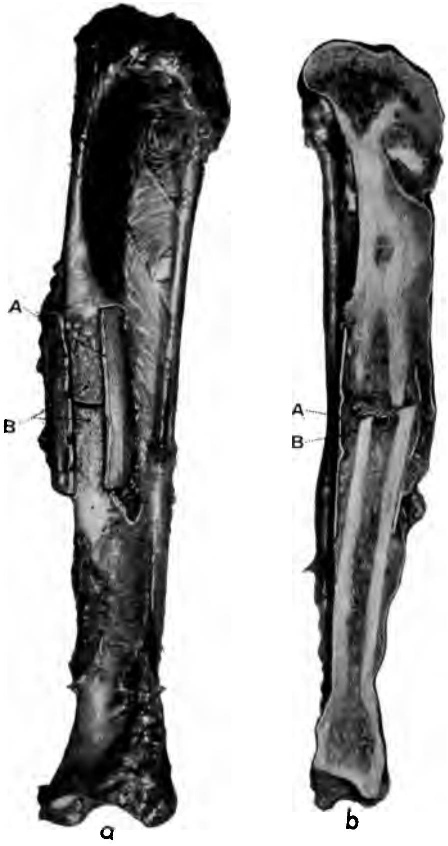


Fig. 56.—Two Cats' Tibias Treated by Metal Collars.

(*a*). No. 10, 10 days after operation. A, Aluminium plate, cut open to show bone ends. B, The outer surface of these is rough and pitted by the granulations of early callus.

(*b*). No. 14, 25 days after operation. Specimen is cut down the middle, without disturbing the aluminium plate (A). There is abundant external callus (B) formed beneath the plate, independently of the periosteum.

When the collar is removed, the underlying bone is " bare," in the sense that it has no soft tissue covering it; but in the early stages it is rough and pitted, from the exudation of the granulation tissue that is to form the external callus, although the periosteum is quite excluded.

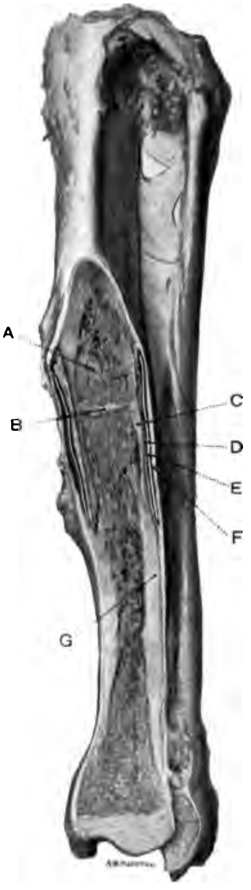


Fig. 57.—Cat's tibia (No. 9), united by steel plate, 52 days after operation. There is very slight external callus, and the deep layer of periosteum is ossified. A remarkable development of internal callus occupies the marrow cavity and the place of the dense bone. A, Internal callus. B, Cartilage still present at line of fracture. C, the much thinned dense bone. D, External callus. E, Steel plate. F, Ossified periosteum. G, Thickening of the dense bone below the fracture.

Fig. **56 *a*** is a cat's tibia (No. **10**, ten days). There is almost no naked-eye evidence of repair, but no necrosis. The surface of the ends of the bone is roughened by very early granulation (callus) formation. ***Fig.*** **56 *b*** is from No. 14 (twenty-five days). There is well-marked callus formation, chiefly present beneath the plate, between it and the bone. Also there is both internal and intermediate callus, but this for the most part is not derived from, or attached to, the actual ends of the fragments, which appear in part to be bare, in a state of necrosis or suspended vitality. The vital union, therefore, is incomplete. These two specimens (***Fig.*** **56**) show well the early stages of external callus formation, derived solely from the bone when the periosteum is excluded.

Fig. **57** is from No. 9 (fifty-two days), and shows a most interesting specimen. The bones have united in good position. The steel plate is covered in by a layer of periosteum. A thin layer of callus lines the deep surface of the periosteum outside the plate, and this is best marked at the two ends, where the periosteum is close to its bony attachment. There is also a distinct thin layer of external callus on the outer surface of the bone beneath the plate. At the site of fracture a feeble repair has taken place, by cartilaginous tissue. The dense part of the shaft of the bone has been almost entirely replaced by an open spongy tissue, there being the thinnest possible shell of compact bone left. It is evident in this case that the closely encircling plate has interfered with callus formation on the outer surface of the bone, and that, as if to make up for this, the medullary circulation being good, the bone activity in the form of osteoporosis and bone reconstruction has proceeded with unwonted vigour in its interior.

From a practical point of view the method is of doubtful value. It clearly interferes with the chief agent of repair, viz., the external callus. If the collar is put on so rigidly as to act as an efficient immobilizing splint, it prevents the laying down of external callus ; if it is put on loosely, so as to allow a callus layer on its interior, it will permit movement, and this often leads to displacement.

Intramedullary Pegs (Bone). (*Table IV.*, p. 163.)—In seven experiments I used pegs made of bone or ivory; but as these were only $\frac{1}{8}$ in. to $\frac{5}{32}$ in. in thickness, they were not strong enough to stand the strain put upon them, and in every case the peg was snapped. From a practical point of view, therefore, this series can be dismissed with few words. It is evident that the muscular force which comes into play after a fracture is considerable. It is evinced also by the fact that when the lower leg was the seat of the operation, the fibula usually was also fractured. But the specimens from this series illustrate very well some of the features of repair in the case of mal-united bones, and also afford examples of the formation of false joints.

Fig. 58 shows, in its early stage, the process by which the mal-position of the fragments is minimized by a filling up of angles and concavities with callus. (*a*) is from No. 5 (seventeen days). Displacement is not complete, so that the ends of the fragments are still in apposition, but with some lateral deviation. The angles between the side of one fragment and the end of the other are filled with callus ; this has not formed at all on the surface of the fragments, which are left jutting out. The useful result of this arrangement is clear : the filling up of angles restores the bone to something of its original form, and supports the strain thrown upon it in the original axis. The interesting point arises, however, as to the factors which cause this purposeful remodelling of the bone architecture. The simplest explanation would be that the lateral displacement of the fragments, as seen in *Fig.* 58 *a*, strips off a portion of periosteum and causes a blood-space, triangular in longitudinal section (shown by the letter **A**), bounded by three surfaces, (1) The outer surface of one end, (2) the cross-section of the other end, and (3) the deep surface of the periosteum. Into this blood-space both the raw bones pour cells which form callus. Where the bone juts out beyond its fellow, the periosteum remains tightly bound to it, and no exudation or callus formation occurs.

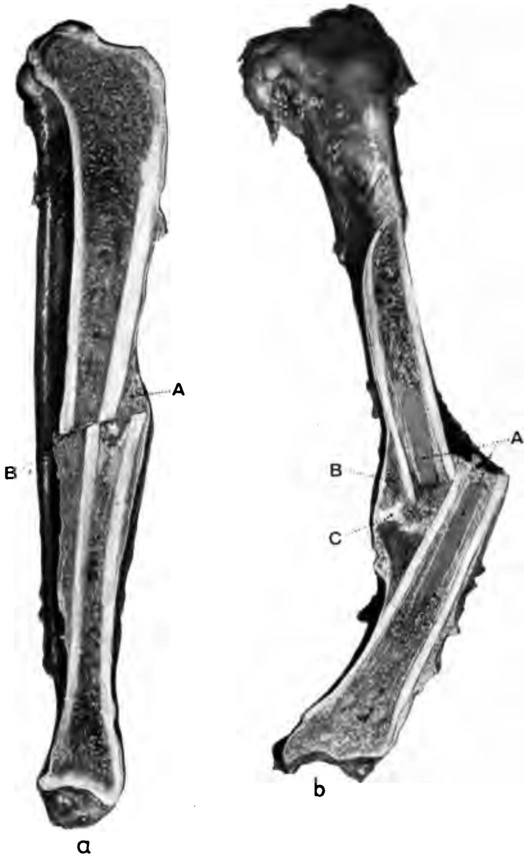


Fig. 58.—Two Cats' Tibias, showing Mal-union after Medullary Bone-Pegs have broken.

(*a*). No. 5, 17 days after operation. A, Early callus filling up the angle between the fragments. B, fracture line.

(*b*). No. 6, 44 days after operation. Mass of callus on the concavity only. A, Broken bone-peg. B, Ossified callus next to the bone. C, Cartilage still remaining at the site of fracture.

Fig. 58 *b* shows No. 6 (forty-four days). Union has occurred with marked angulation, the concavity of which is filled by callus, partly cartilaginous and partly ossified. That part of the callus which is first formed and is liable to least movement is in the angle between the periosteum and the bone. This is

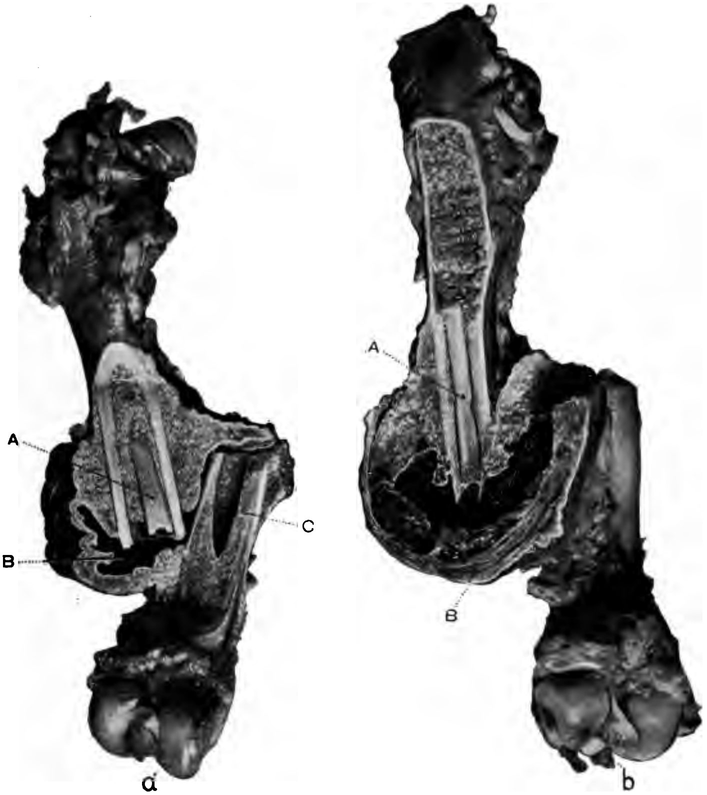


Fig. 59.—Femurs of Two Rabbits, showing the Formation of False Joints after the giving way of Medullary Bone-Pegs.

(*a*). No. 15, after 32 days. There is abundant callus formation, especially from the upper end. A, Upper fragment of the broken peg. B, Cavity of the false joint. C, Cavity from which the lower half of the peg has fallen out.

(*b*). No. 20, after 47 days. Here, too, there is abundant callus formation. A, Broken peg. B, Fibrous capsule of the false joint.

ossified. The part opposite the site of fracture, where movement has continued longest, is still cartilaginous. Here again, the filling up of the concavity of the fracture by callus seems to be determined by the fact that it is at this site that the periosteum is loose and allows exudation. In general terms, therefore, it may be said that in irregular fractures with malposition, the deposit of callus is determined by an absence of tension, which favours the exudation of bone cells from the ends of the fractured bones.

In *Figs.* 59 *a* and *b* are seen two specimens of femurs of rabbits showing the formation of false joints : *a* is after thirty-two days, and *b* after forty-seven days. In both there is abundant callus formation, showing that in these cases it is the excessive displacement and mobility which cause the non-union, rather than any absence of reparative capacity. In this respect these cases contrast with the two specimens already figured (*Figs.* 50, 51) in which a scantiness of repair associated with the age of the bones seems to determine the condition. In one respect, however, all the four specimens of false joint which I have encountered in these experiments are similar : they all occurred in either the femur or the tibia of a rabbit, that is to say, in a part of the limb where there is only a single bone (the fibula is only a rudimentary spicule in the rabbit). This would show that free mobility is an important factor in the production of this condition. As to another factor often cited as a cause of false joint, viz., the interposition of the soft parts, none of my experimental cases showed any evidence of this.

Intramedullary Pegs (Decalcified Bone). (*Table V.*, p. 164).—These experiments, five in number, met with no success. The peg always gave way and displacement occurred. For practical purposes, therefore, nothing more need be said. Two of the specimens call for comment.

Fig. 60 *a* shows No. 12 (twenty-nine days). There is a large callus mass filling up the angle between the fragments. In this it is easy, even with the naked eye, to trace two stages : (1) Just outside the dense bone of the shaft is a narrow irregular zone of ossification ; (2) All the rest of the callus is of a semi-cartilaginous consistency, having originated from the bone.

Now, the ossified portion is the oldest part of the callus, and therefore the position of the ossification points to the originating point of the callus. This, in the specimen, has clearly been from the outer surface of the bone, and not from the deep surface of the periosteum.

Fig. 60 *b* shows No. 39, which is one of the cases of almost entire absence of union with which one is occasionally confronted in bone repair after operation. It is a cat's tibia (twenty-eight days). The skiagram shows practically as much as the specimen itself. The position has been well maintained by a few turns of aluminium-bronze wire outside the periosteum, which embraced the two obliquely cut ends ; but there is not a trace of any kind of callus or reparative material. The ends of the fragments of bone beyond the wire are necrosed. The section of the bone and the insertion of the peg must have injured their

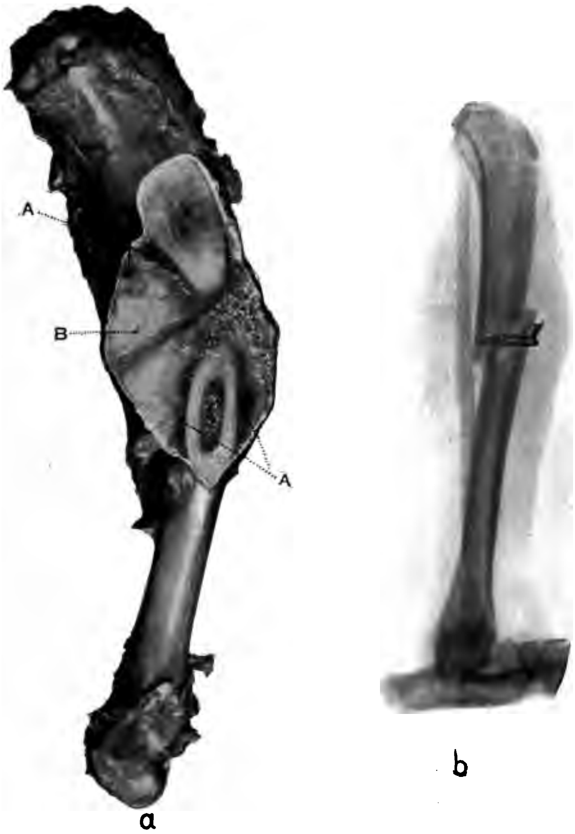


Fig. 60.—Two Cats' Tibias, showing Mal-union after the Use of Decalcified Bone-Pegs.

(*a*). No. 12, after 29 days. A large mass of callus is present, chiefly in the concavity of the fragments. A, Ossification of the callus taking place from the surface of the bone. B, Wedge-shaped cartilage under the periosteum.

(*b*). No. 39, after 28 days. Skiagram showing the encircling wire and the displacement. There was no callus.

deep blood-supply, whilst the wire interfered with the surface vessels. There is probably a third factor in the matter; I have constantly found that specimens in which aluminium-bronze wire has been used show marked green discoloration of the tissues, and it is likely that this copper absorption may hinder tissue growth.

The specimen is most significant as to the origin of the reparative material from the cut surface of the bone. The experiment is represented by the diagram in *Fig.* 61, which shows that the obliquely cut bone ends have slid into the position shown. In normal circumstances healing would occur by the angles A and B being filled by callus. Now the side of each angle formed by the cut bone is dead, and the other side of the angle is the outer periosteal surface: hence no callus is formed.

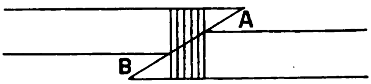


FIG. 61.

Intramedullary Pegs (Gelatin and Catgut). (*Table VI.*, p. 165.)—The pegs were made by running gelatin into moulds in which were strands of No. 1 chromic catgut. By this means the pegs, which were hardened in formalin, were prevented from becoming brittle. Only four experiments were performed, all on cats' tibias. The gelatin softened too quickly to allow of any real fixation by this means. Wire, which was used to introduce the pegs, was also wound round the oblique fractures, and it was evidently this wire more than the intramedullary splint that kept the bones in position. In two specimens, No. 34 (twenty-two days) and No. 40 (twenty-eight days), there is no repair of any sort near the fracture. The encircling wire has produced necrosis of the ends of the bones in just the same way as in No. 39 of the last series.

Fig. 62 *a* shows No. 41 (twenty-eight days); there is early union by external callus in good position, but there is no bony union, and part of the ends appears necrosed.

Fig. 62 *b* shows No. 33 (forty days); there is a further stage of union by thick spongy external callus, which is partly ossified, but this is not firm enough to prevent considerable movement between the fragments.

I account for the failure of, or weak, union in these cases by the fact that both intramedullary and periosteal means of fixation were used, thereby interfering with the blood-supply of the bone ends, both from within and from without.

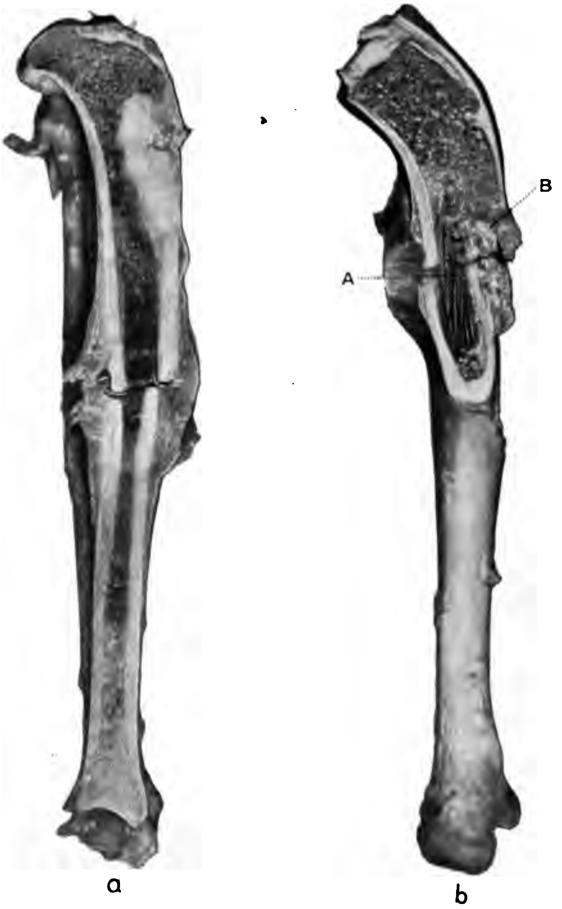


Fig. 62.—Two Cats' Tibias after the use of Medullary Pegs made of Catgut and Gelatin.

(*a*). No. 41, after 28 days. Union by external callus. Actual bone ends show partial necrosis.

(*b*). No. 33, after 40 days. A, Remains of catgut peg. B, External callus. Here, too, the actual cut surfaces of the bone show but little repair.

Intramedullary Pegs (Horn).—I only tried horn (which has been spoken of so highly by Rehn) on one occasion. It behaved just like bone or decalcified bone; that is to say, it broke, and allowed great displacement of the fragments. It is evident that it would only be of use when supplemented by external splints, and therefore I did not think it worth while to pursue the matter.

Intramedullary Pegs (Metallic Magnesium). (*Table VII.*, p. 166).—It is a well known fact that metallic magnesium is readily disintegrated and absorbed in the living tissues. It seemde, therefore, worth while to try the effect of this metal when used as an intramedullary peg; and the experiments, which were six in number, produced most interesting results.

In four, the femur was the bone used, once of a cat and three times of rabbits. In all of these great displacement occurred, three times from the breaking of the peg, and once from the breaking of the shaft of a rabbit's femur. In the first three there was the same excess of callus and new bone that is seen in the tibial specimens, and in two of them (Nos. 22 and 30) the condition was one of periostitis with the formation of abscess cavities. Even in those two specimens where the process was less severe (Nos. 29 and 38), there is a great periosteal thickening of the bone running some distance along the shaft in both directions. The two experiments on the cats' tibias are the best illustration of the results of this method. In both, the anatomical position and the function were good, but there was great excess of callus.

Fig. 63 *b* shows No. 37 (fifty-five days). At the seat of fracture there is spindle-shaped thickening of the bone to about double its natural size. This consists of well-ossified callus, by which the bone is firmly united. In the marrow cavity is seen the disintegrated remains of the peg, in the form of opaque whitish masses, interspersed with red material (blood-clot and tissue cells).

Fig. 63 *a* shows No. 35 (sixty-six days). The union is not so good, and the fibula has undergone fracture. Here, too, there is a great callus mass, by which the tibia and the fibula are united to one another. Practically none of the metallic peg remains as such. In the callus there are some islets of cartilage.

It is evident from these specimens that magnesium is rapidly disintegrated and absorbed from the medullary cavities of bones. This disintegration is too rapid to allow reliance to be placed on such pegs as the sole means of fixation ; but in the process of its absorption, the magnesium evidently acts as a most powerful stimulant to bone formation. Indeed, it acts as an irritant which may so stimulate the bone as to cause a definite periostitis.

This property makes the use of magnesium pegs undesirable in the treatment of ordinary fractures. But it seems to me that if one had to deal with an old un-united fracture, where bone-formation was in abeyance, the method would offer very great advantages, and I should be inclined to adopt it if occasion offered.

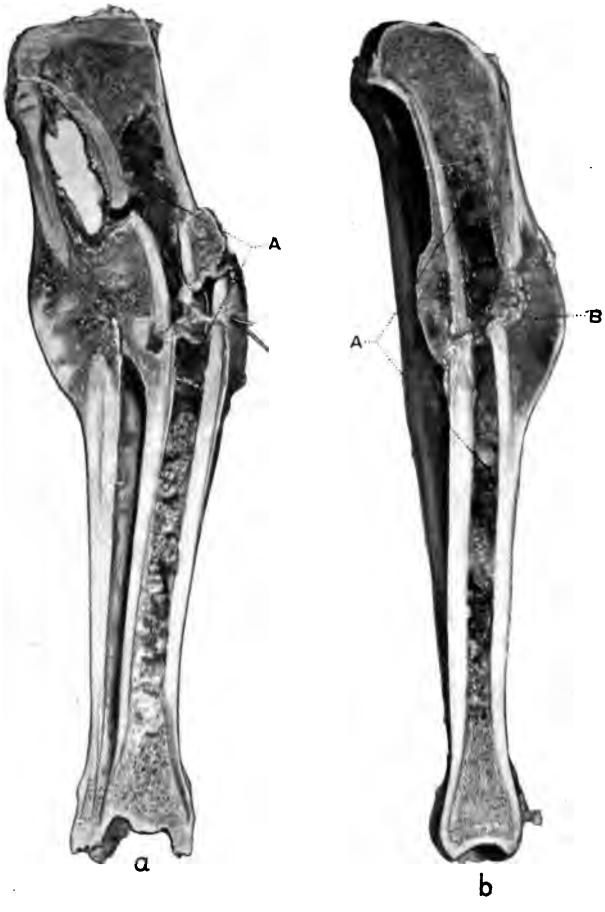


Fig. 63.—Two Cats' Tibias after the use of Magnesium Pegs.

(*a*). No. 35, after 66 days. A, Remains of the peg. There is fracture of the fibula, and great callus excess in both bones.

(*b*). No. 37, after 55 days. A, Remains of the peg. B, Excessive external callus, firmly ossified.

Intramedullary Pegs (Steel). (*Table VIII*, p. 167.)—None of the foregoing pegs being rigid or strong enough to be reliable for experimental work, I tried solid pegs made of nickel-plated steel. These were of different thicknesses, from $\frac{1}{8}$ in. upwards, varying by $\frac{1}{64}$ in., and $1\frac{1}{2}$ in. long, pointed at both ends. Some were provided with a fixed cross-piece at the centre and inserted into one fragment, the other fragment being brought over the projecting half. This was the easiest method in the case of the femur. When working with the tibia, it was impossible to separate the ends of the bone enough for this manœuvre, and a different one had to be adopted. The pegs were perforated at their middle by a fine hole transverse to their long axis. The sides of the pegs were grooved along their whole length, and the ends of the transverse hole opened into the grooves. A fine steel wire was threaded through the peg, and its ends were laid along the grooves. The peg was then completely pushed into one fragment, the two fragments brought into line, the ends of the wire pulled upon, and the peg thus drawn up into the other fragment, so that the half peg lay in each half of the bone. The ends of the wire were then twisted together and cut short.

The number of these experiments was seven. Every one succeeded, judged from the point of view of function. In one case (No. 47, *see Fig.* 65 *c*) a rabbit's femur was split by the peg at the moment of introduction. This led to a badly comminuted fracture, which was encircled by wire. With the exception of this case, all gave a good anatomical result.

As regards the reparative process, a very marked difference was observed in the behaviour of the femur and the tibia. In the former there was some tendency to callus excess; in the latter, repair was distinctly sub-normal.

There were four experiments on the femur (two cats, two rabbits). In both the cats' femurs (Nos. 43 and 44, seen in *Figs.* 64 and 65, *a* and *b*), the period of observation was six weeks. In one, repair was complete, by a firm external callus and union of the bone ends. In the other, there was rather more callus, but this was partly cartilaginous opposite the line of fracture, and bony union was not complete. In both the rabbits' femurs there was firm though excessive callus, and bony union at periods of thirty-four and forty-three days.

The specimen in which there was the firmest and earliest union was the comminuted case (No. 47, *Fig.* 65 *c*). The peg lies in a comparatively large central cavity, round which there is a shell of new bone nearly ¼ in, thick, evidently the result of callus formation and ossification round each bone splinter as a centre. This specimen affords evidence of the activity of the bone itself in the process of repair. Instead of repair occurring only from the cut surfaces of the bone, it took place from every separate fragment.

The tibial experiments (*Fig.* 64 *c* and *d*, *Fig.* 65 *d* and *e*) appear at first sight to be even more successful than the femoral. In each of the three cases the bones were in perfect alinement, and the limb was of perfect function ; but on cutting open the bones, the process of repair is seen to be defective.

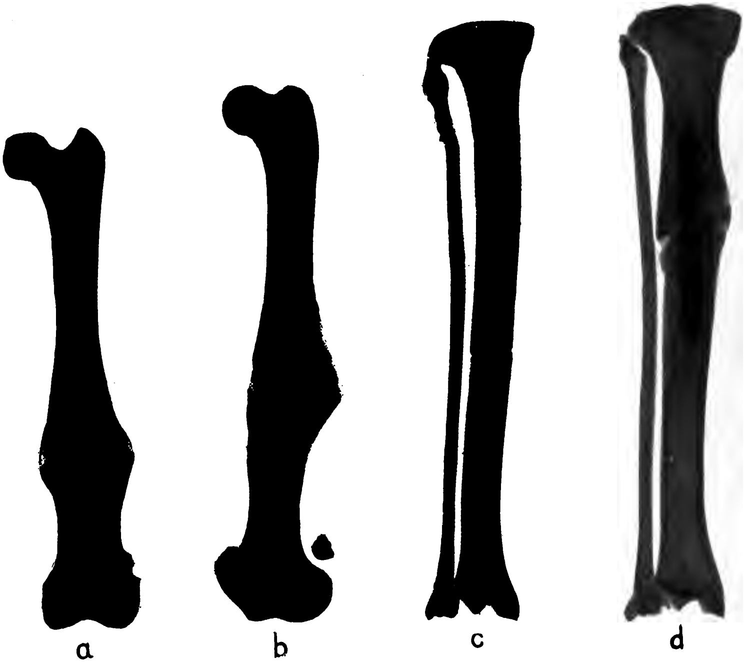


Fig. 64.—Skiagram of Bones after the Use of Steel Medullary Pegs.

(*a*). Cat's femur (No. 43), after 42 days.
(*b*). Cat's femur (No. 44), after 42 days.
(*c*). Cat's tibia (No. 51), after 14 days.
(*d*). Cat's tibia (No. 56), after 34 days.

Figs. 64 *c* and 65 *d* show No. 51 (fourteen days). The animal was unhealthy, and died at the end of a fortnight. There was no callus and no repair.

Figs. 64 *d* and 65 *e* show No. 56 (thirty-four days); there is moderate callus and early bone union, with the formation of some cartilage at the point of fracture.

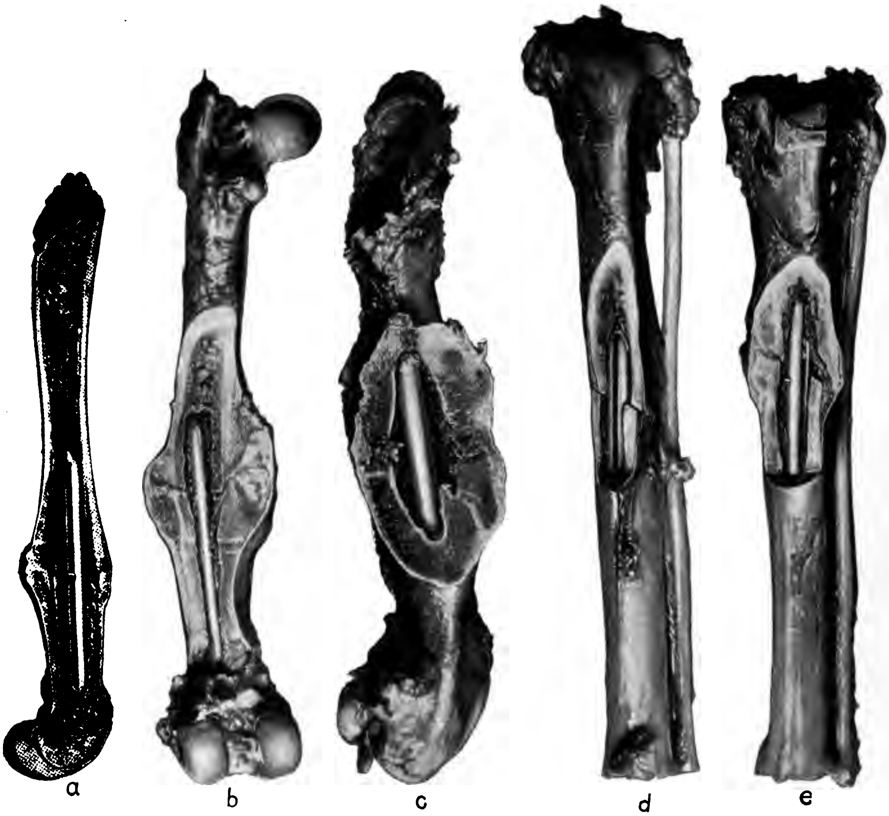


Fig. 65.—Bones after the Use of Steel Medullary Pegs.

(*a*). Cat's femur (No. 43), after 42 days. Firm union by ossified external callus.

(*b*). Cat's femur (No. 44), after 42 days. Firm union, with some excess of external callus. This is still cartilaginous at the line of fracture.

(*c*). Rabbit's femur (No. 47), after 34 days. Bone was splintered by the insertion of the peg, and the parts were surrounded by wire. The peg lies in the centre of a cavity whose walls are formed by a thick layer of new bone formed from the splintered bone.

(*d*). Cat's tibia (No. 51), after 14 days. There is no evidence of repair.

(*e*). Cat's tibia (No. 56), after 34 days. Union is chiefly by external cartilaginous callus.

In No. 50 (forty-two days) there is no repair visible; the ends of the bone appear to be cut clean and not rounded off, and there is neither effusion nor callus surrounding the seat of fracture.

In this case, both ends of the bone had to be bored to take the ⅛-in. peg, which fitted tightly. Probably in the course of the operation the periosteum was raised from the bone ends to some extent, and thus the actual cut surfaces of bone were rendered avascular.

Several points are clear. In all, there was anatomical and functional success. In those cases (the femurs) where the peg fitted loosely, there was good union, but callus excess. In the cases (the tibias) where the peg fitted tightly, the repair was delayed. In none of these cases was there any inflammatory or septic complication. This latter fact shows the tolerance of the bones towards foreign bodies of comparatively large size, provided that they be firmly fixed, and not chemically affected by the tissues.

Intramedullary Pegs (Wire Spirals). *Table IX*, p. 168.)—One objection to the non-absorbable peg is that it leaves a large foreign body inside the bone, and if at any time inflammation or sepsis occurs, it will be very difficult to remove it, and the removal will endanger the continuity of the bone. I have endeavoured to meet this by the construction of wire pegs of longitudinally placed strands surrounded by circular turns, and so made that by leaving the end of the wire outside the bone, the whole peg could be removed by pulling on this end. I may say that in this experimental work I have not been able entirely to succeed, simply because the size of the bones is so small that the spiral cannot be made sufficiently rigid, and the wire is so thin that very often it breaks when pulled upon. In two cases I have succeeded in removing the peg without disturbing the fracture, and I think that with bones having a marrow cavity which will take a ¼-in. or larger peg, it is perfectly possible.

However, these specimens, apart from the immediate object with which they were connected, show some points of interest. In nearly all there was marked angulation from a bending of the peg, and in four out of six there was some sepsis. This latter is of interest in its origin. The technique was exactly the same as when using the solid pegs. Why then was there so much greater liability to sepsis ?

The answer to this is found, I think, in the fact that the bones were allowed too free mobility. This produces an excessive effusion, which leaks through the wound, and this leakage causes a contamination from the skin, whilst the copious effusion in the tissues gives an ample soil for the growth of bacteria. The sepsis was trivial, but nevertheless quite important enough completely to modify the aspect of the case.

In all cases there was great thickening of the bones, with excess of callus. This was brought about partly by the over-stimulation of mobility, and partly by the inflammatory irritation.

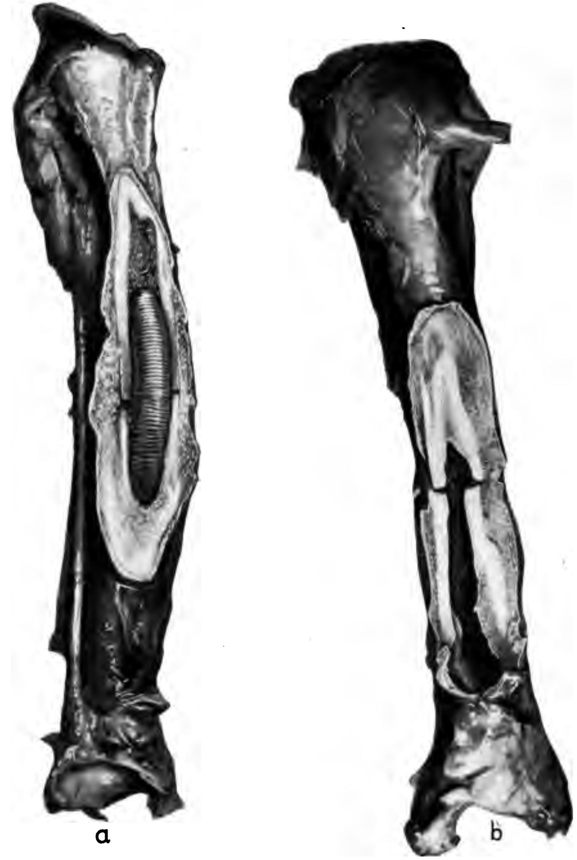


Fig. 66.—Two Cats' Tibias after Union by a Wire Spiral Intramedullary Peg.

(*a*). No. 64, after 28 days. The peg is still in position. Great periosteal thickening.

(*b*). No. 77, after 14 days. The peg has been removed by unravelling before the specimen was dissected. There is great periosteal thickening. In both cases sepsis occurred, and in both the actual bone ends show no sign of repair.

Fig. 66 *a* is from No. 64 (twenty-eight days). The wire spiral is still in position, and the great periosteal thickening is well shown.

Fig. 66 *b* is from No 77 (fourteen days), and shows the fracture in good position and undisturbed by the removal of the wire, which had been drawn out before opening the bone.

I think a comparison of the experiments with solid metal and those with wire spiral pegs affords the most convincing demonstration that imperfect fixation, and not the presence of a foreign body, is responsible for both callus excess and the formation of a septic sinus ; for in all respects, except that of the rigidity of the peg, these cases were similar. In the one series there was never any sepsis, but in the other it occurred generally.

Transfixion and Extension Apparatus. (*Table X*, p. 169.)—All the foregoing operative methods involve a direct attack upon the seat of injury. It is a matter of great importance to compare with these a method which fixes the broken bones without the exposure of the site of fracture—a method which, whilst maintaining extension, does not rigidly fix the broken ends to one another. For practical purposes this is important, because it illustrates the principles of extension so widely used in human surgery ; and on theoretical grounds it is important, because it gives, as no other method can, the stages in repair, uncomplicated by displacement of or interference with the parts concerned by any foreign bodies. The method I adopted was as follows : The tibia was perforated at either extremity through minute skin openings by holes which were two and a half inches apart. In order that these should be exactly parallel with one another, the drills were guided by openings in a metal block perforated by parallel holes at the proper distance. Through the holes in the bone were passed two round rods 1 in. long and ⅛ in. thick, cut at each end with a screw thread for a nut. Then through an incision the bone was divided by the fret-saw about the middle. The incision is closed in layers, and the parts are clamped into position by placing thin steel bars 2½ in. long on each side, so as to take the ends of the transverse bars. The rectangle thus formed is fixed by four nuts and washers.

This method proved to be simple and very efficacious. The animals ran about with the steel frame in position, and in only one case (the first, when I had not got the suitable drills) was there any sign of inflammation round the transfixion holes. Two cats of this series died of distemper (Nos. 58, 65). In one of these no repair was evident at the end of eighteen days, but in all the other five cases repair proceeded regularly. It will be convenient to describe these five in the order of the length of period during which they were under observation.

Figs. 67 and 68 are skiagrams showing some of the specimens at intervals varying from seven to seventy days. They show how well the position of the bones is maintained, and how little irritation occurs at the site of perforation.

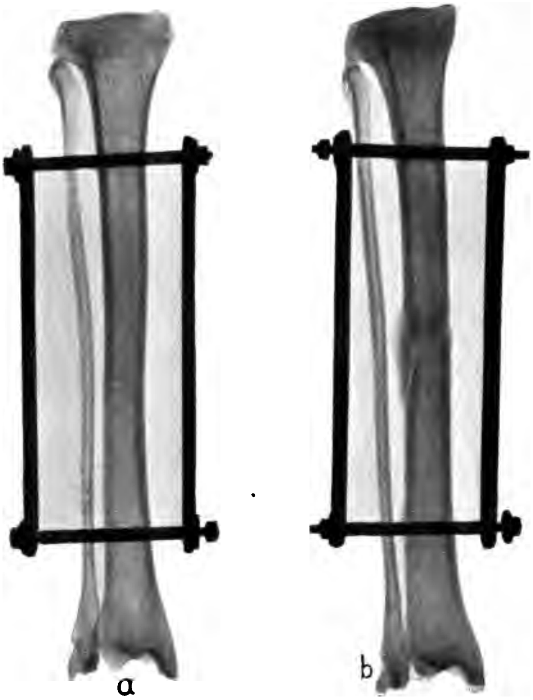


Fig. 67.—SKIAGRAMS OF CATS' TIBIAS TREATED BY TRANSFIXION.
(*a*). No. 65, after 7 days.
(*b*). No. 57, after 14 days.

Fig. 69 *a*, No. 65 (seven days), shows merely a small quantity of blood-clot beneath the periosteum and in the marrow cavity.

Fig. 69 *b*, No. 57 (fourteen days). There is a layer of external callus, about the same thickness as that of the compact bone beneath. The callus is uniformly calcified, and extends about $\frac{1}{4}$ in. above and below the fracture. Inside the marrow cavity there is a very definite internal callus plug in the upper, but not in the lower fragment. The line of bone division is still clearly defined. There is a curious islet of cartilage in the marrow cavity of the upper fragment, about half an inch from the fracture.

Fig. 70 *a* shows No. 55 (twenty-one days). The same condition is seen as in the last case, except that the external callus is distinctly cartilaginous. The same difference as in the last specimen is seen between the upper and lower fragment in respect to the presence of internal callus in the former and its absence in the latter.

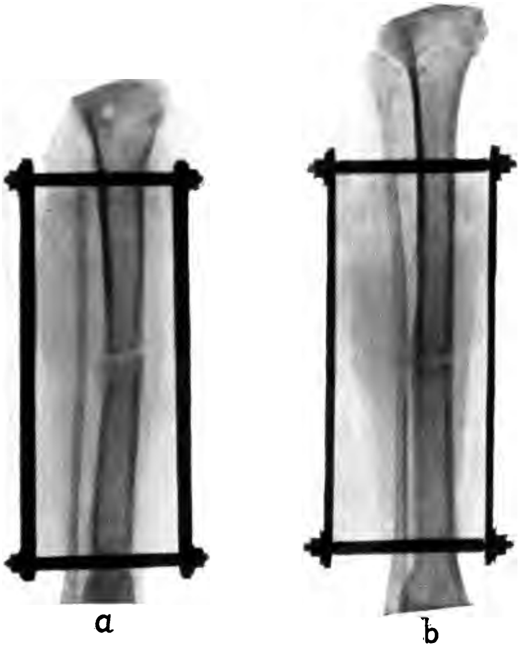


Fig. 68.—SKIAGRAMS OF CATS' TIBIAS AFTER TRANSFIXION.
(*a*). No. 60, after 57 days.
(*b*). No. 59, after 71 days.

Fig. 70 *b* shows No. 60 (fifty-seven days). The bone is firmly united, and only a linear trace of the fracture can be seen on naked-eye examination of the section. There is a small amount of external callus and a solid internal callus. This and the following specimen represent the most perfect union that I have ever attained in experimental operations.

Fig. 70 *c* shows No. 59 (seventy-one days). Exactly the same conditions are found as in the last case, i.e., a solidification of the fracture, together with a minimum amount of external

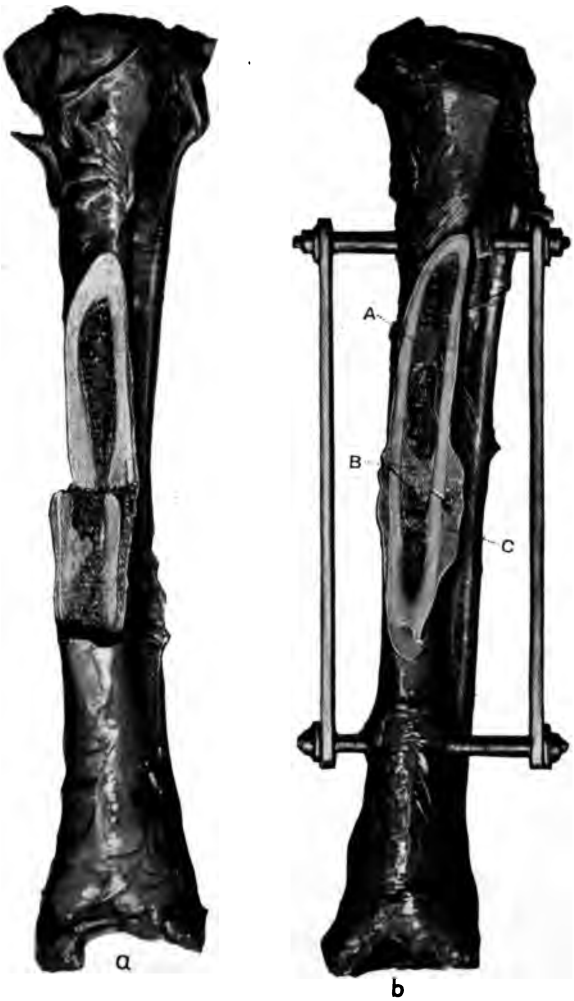


Fig. 69.—Cats' Tibias after Transfixion.

(*a*). No. 65, after 7 days. The ends of the bone have a small quantity of blood and granulation tissue between them.

(*b*). No. 57, after 14 days. Early ideal repair. A, Islet of cartilage present in the medulla far from the fracture. B, Internal callus, present only in the upper fragment. C, External callus.

and internal callus. It is especially interesting as showing the complete absence of irritation at the two points where the bone is perforated and in which steel bars have been resting for over ten weeks.

There can be no doubt, as far as the evidence of these experiments goes, that this method of indirect fixation of the fracture

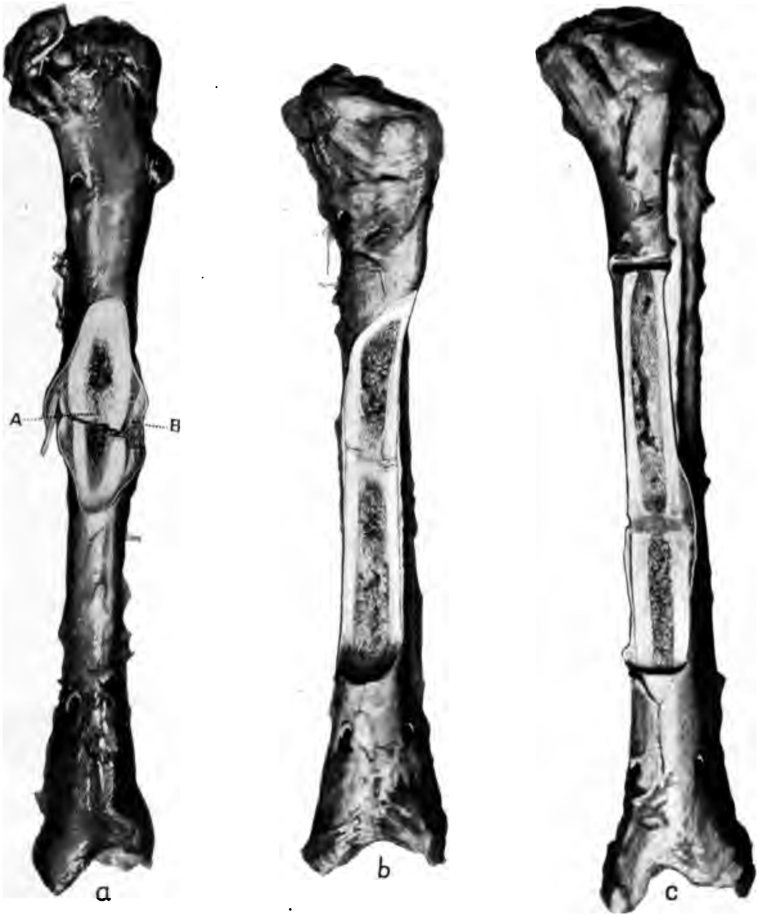


Fig. 70.—CATS' TIBIAS AFTER TRANSFIXION.

(*a*). No. 55, after 21 days. A, Internal callus present only in the upper fragment. B, External callus.

(*b*). No. 60, after 57 days. Perfect internal and intermediate callus.

(*c*). No. 59, after 71 days. Perfect union by means of a minimum of callus.

gives a more perfect union of the bones than any direct method that I have performed. It may be objected that the experimental conditions, in which fixation is provided for before any displacement has taken place, are much more favourable than can be attained in human surgery. But, on the other hand, in every one of these cases the periosteum has been divided and the bone cut by a straight smooth saw-cut, both of which conditions are unfavourable to repair in comparison with those obtaining in simple fractures, where the periosteum is often not severed and the jagged bone-break gives a far better surface for repair.

The small quantity of callus formed is noteworthy, and is associated, no doubt, with the absence of friction between the bone ends.

COMMINUTED FRACTURES.

The use of the transfixion apparatus described in the last section rendered it comparatively easy to undertake the study of comminuted fractures. The technique of these operations was the same as the last, except that the bone was crushed by a forceps for a distance of about 1½ in., instead of being divided by a fret-saw. After this had been done, one of three different courses was pursued :—

(1) *The fragments and periosteum were left in situ ;* or (2) *All the loose fragments were removed, but the periosteum was left ;* or (3) *The broken bone was surrounded by a thin aluminium plate, which excluded the periosteum from the fragments.*

In all cases the soft parts and skin were closed over the site of fracture. It will be convenient to describe the results of each class separately, before discussing the merits of this method for the treatment of severely crushed bones.

1. **Fragments and Periosteum Left in Situ.** (*Table XI*, p. 170.) —The three cases in this series (shown in *Fig.* 71 *a*, *b*, *c*) are all cats' tibias. The period of observation was twenty-eight days in two cases and forty-two in the third. In two (Nos. 67 and 72) the position was well maintained, and except for some thickening of the bone in No. 72, the bones were restored to a close approach to the normal form. The functional results were uniformly good. The animals after the first week used the injured limb quite freely, and often ran without any appreciable limp.

The union in all these cases was firm and solid, the fragments being embedded in callus. In fact, these cases exhibit the most rapid and firm union of any experimental fracture that I have seen.

Fig. 71 *a* shows No. 67 (twenty-eight days). There is firm union in good position without callus excess. There seems to

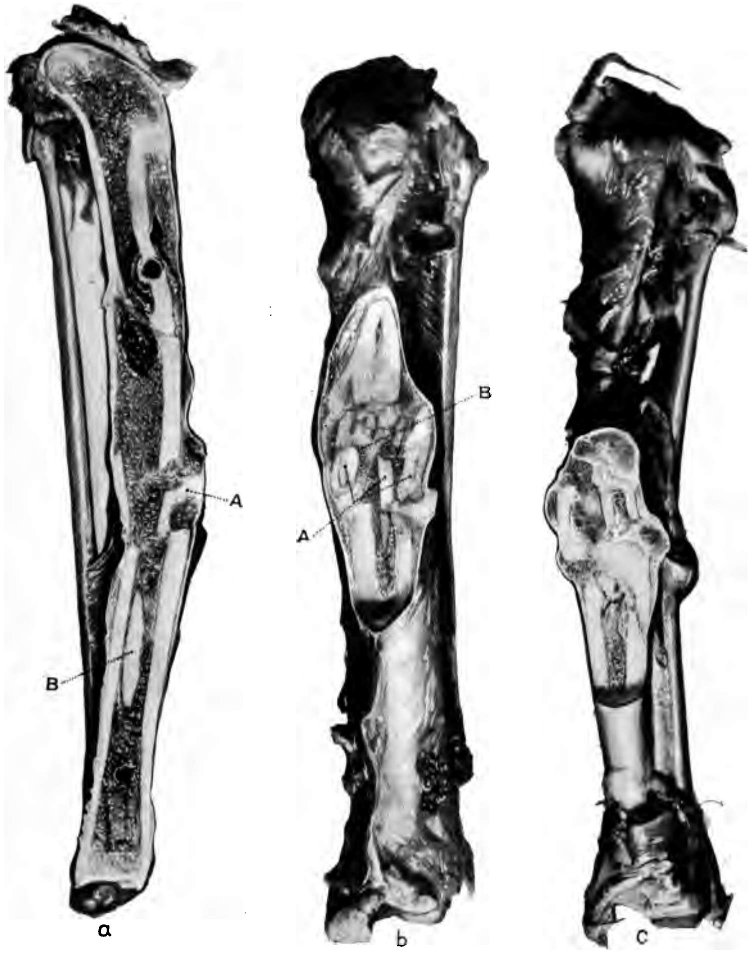


Fig. 71.—CATS' TIBIAS. COMMINUTED FRACTURE. FRAGMENTS LEFT IN SITU.

(*a*). No. 67, after 28 days. A, One of the fragments. B, A fragment which has slipped down into the marrow cavity.

(*b*). No. 72, after 28 days. A, Small fragments of bone. B, Callus growing from these fragments.

(*c*). No. 68, after 42 days.

have been a posterior splinter of bone left connecting the main fragments, which would therefore have served to keep the parts more firmly fixed than in those cases where there was complete solution of continuity. In the upper fragment the medullary cavity is filled by a firm mass of callus extending about half an inch from the fracture. This is less marked in the lower fragment.

Fig. 71 *b* shows No. 72 (twenty-eight days). There is a large, spindle-shaped mass at the site of injury. The line of the bone is well preserved. The thickening consists of all the fragments welded together in firm callus, which is in an advanced stage of organization, so that there is solid union of the fracture. In this mass, surrounded by the periosteum, there is no distinction between external and internal callus ; but the dense fragments of bone can be distinguished from the intervening callus with its more open structure. There is, in fact, a strong and solid union.

Fig. 71 *c* shows No. 68 (forty-two days). There has been some fault in the upper transfixion hole. Either this was made too large, or else it became enlarged by inflammation. The result has been that fixation was not secure, and the fibula has fractured and the bones are angulated. There is the same solid mass of bone fragments embedded in callus as in the preceding specimen.

2. **Fragments Removed.** (*Table XII*, p. 170.)—There were four experiments, upon cats' tibias. In one the lower transfixion hole had been made through the front surface of the bone, and the transfixion bar had worked loose. In this the fibula had broken and the tibia was angulated. In all the others the anatomical result was good. The functional condition was not so good as in the last series, and the animals appeared reluctant to place their weight on the leg, so that although they could walk, this was with a marked limp.

As regards repair, all the specimens show the same general condition, with remarkably little difference according to the period (varying from three to six weeks). To the naked eye, the longitudinal section shows that the continuity of the bone is restored with great exactness ; but the material of repair is merely fibrous or cartilaginous callus, with but little evidence of ossification.

Fig. 72 *a* shows No. 69 (twenty-one days). There is marked angulation. The whole space between the bone ends is occupied by a mass of fibro-cartilage, which merges into the structure of the dense bone by a callus of firmer texture.

Fig. 72 *b* shows No. 70 (forty-two days). The restoration of the form of the bone is almost exact, but the gap between the bone ends is filled by cartilaginous callus.

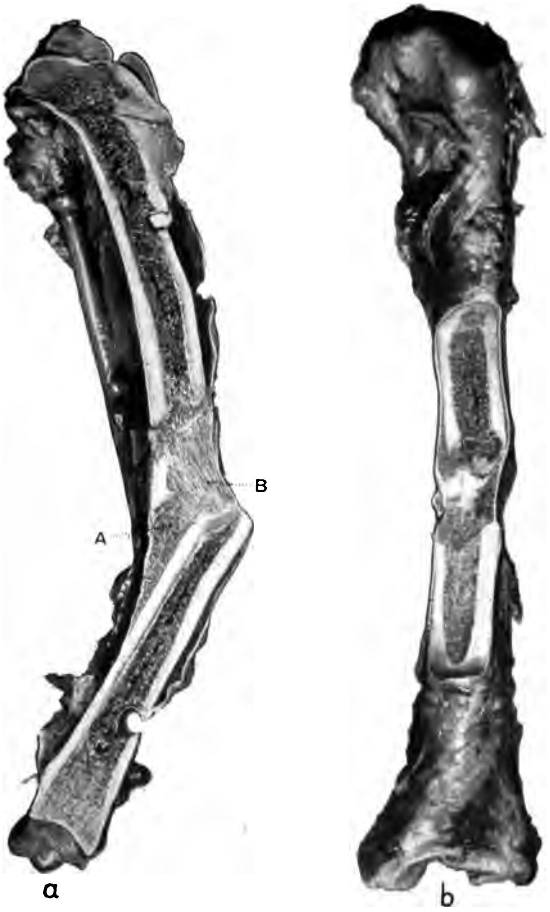


Fig. 72.—CATS' TIBIAS. COMMINUTED FRACTURE. FRAGMENTS REMOVED.

(*a*). No. 69, after 21 days. A, Ossified callus on the surface of the lower fragment. B, Fibrous callus in the middle of the gap. There is one small piece of bone in this gap, but from its firm texture and sharp outline it is evidently a fragment which has been left, and not a new formation.

(*b*). No. 70, after 42 days. Callus is ossified where it touches the bone ends, but cartilaginous in the centre.

Fig. **73** *a* shows No. **71** (twenty-one days). The alinement is good. The gap between the bones is not completely filled to the same thickness as the shaft.

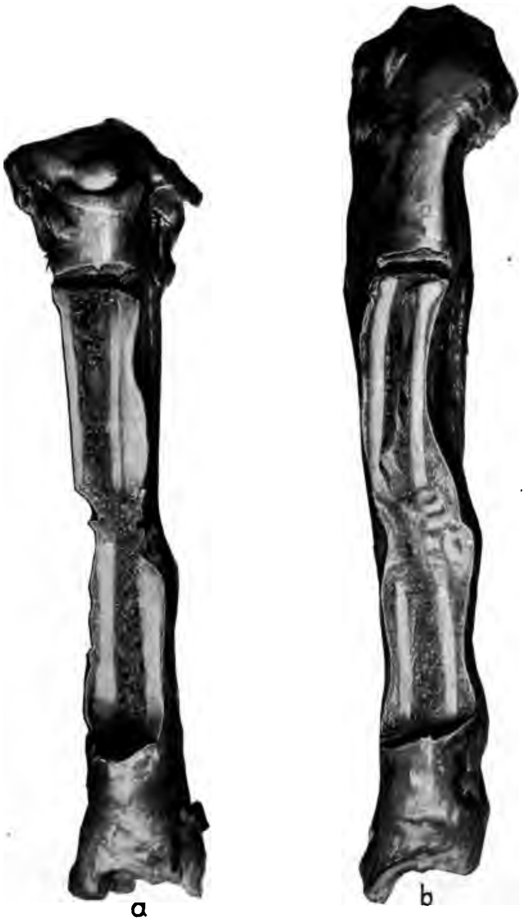


Fig. 73.—Cats' Tibias. Comminuted Fracture. Fragments Removed.
(*a*). No. 71, after 21 days.
(*b*). No. 73, after 28 days.

Fig. **73** *b* shows No. **73** (twenty-eight days). The union has a very solid appearance, but it consists of cartilage, in which there are a few islets of a more calcified material.

An interesting fact in this series is the great contrast afforded by the *x*-ray pictures and the naked-eye appearance of the specimens. In the one (*Fig.* 74) it looks as though there was nothing filling up the gap between the ends of the bone, whilst in the other (*Fig.* 72 *b*), continuity appears to have been completely restored.

3. **Exclusion of Periosteum.** (*Table XIII*, p. 171.)—Only four experiments were made, and two are of no value. In one (No. 74) the animal died the day following the operation, from some undetermined cause; and in the other (No. 76) sepsis occurred, and all the fragments underwent necrosis.

The remaining two specimens, Nos. 78 and 75, were of periods of thirty-five and forty-two days respectively; in both there was a good anatomical result, and in one (75) the animal walked well.

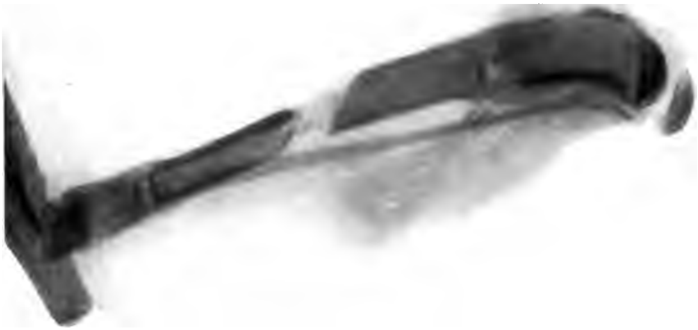


Fig. 74.—Skiagram of cat's tibia (No. 70), 42 days after comminution and removal of fragments. Contrast the apparent absence of repair with the drawing of the same specimen in 72 *b*.

Fig. 75 *a* shows No. 75 (forty-two days). The bone is in good alinement. The small fragments are joined to one another and to the upper half of the bone by firm callus, but there is still some mobility possible between the fractured fragments and the lower half of the bone. There is very definite advanced internal callus present between the small fragments and the upper half of the shaft. Between the dense bone and the plate there is a thin layer of soft material like lymph, but no callus. The periosteum is in a very different condition in different parts of the longitudinal section. On the left, it appears to be perfectly unchanged, neither thickened nor ossified. On the right, it presents a definite firm layer of tissue about $\frac{1}{16}$ in. thick, Above and below, this layer is continuous with the shell of external callus on the outer surface of the main halves of the bone; here it is thicker, and is certainly ossified. In the centre, the periosteal bridge is thin and soft. Between the ends and the centre there are transitional areas of cartilage. This structure

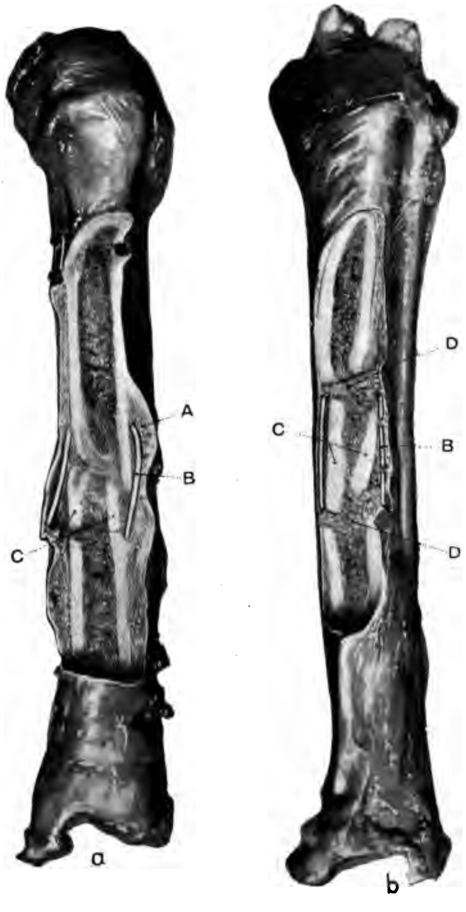


Fig. 75.—Cats' Tibias. Comminuted Fractures, surrounded by Aluminium Plates.

(*a*). No. 75, after 42 days. A, External callus growing from the angle between the bone and the periosteum. B, Plate. C, Separate fragments of bone.

(*b*). No. 78. after 35 days. B, Plate. C, Separate fragments. D, Internal callus at junction of the comminuted part with the main parts of the shaft above and below.

shows that the subperiosteal callus layer is being laid down in the angle of junction of the periosteum and bone, and not by the whole of the deep surface of the periosteum..

Fig. 75 *b* shows No. 78 (thirty-five days). It reveals a rather tardy union of the bones, and there is distinct mobility between both the main parts of the bone above and below and the comminuted portion in the centre. This latter exhibits a marked thickening of the fragments. No external callus is visible outside the metal plate, and the periosteum appears to be quite unchanged. There is some internal ossified callus at the junction of the comminuted part with the main parts of the bone at each end.

Both these specimens show that the comminuted fragments are the centre of active reparative changes, although isolated from the periosteum. At the same time these changes are much delayed, and their vigour impaired, by the periosteal exclusion.

In considering this series of eleven comminuted fractures, there are several important conclusions to be drawn.

From the practical standpoint it is evident that the method of indirect fixation of the ends of the bone, leaving the site of fracture untouched, is a good one. It is a method which will be of great utility in dealing with both compound and comminuted fractures in surgical practice. The length and alinement of the bone are accurately preserved, and at the same time the joints above and below the fracture can be exercised from the very first. It combines the advantages of the methods of extension with those of the methods of early massage and movements.

Next, as to the origin of the reparative callus. This is seen to arise from the bone itself rather than from the periosteum. When there is much raw bone surface, the callus forms from many centres and is rapidly matured. Where the bone fragments are removed, callus is poured out into the periosteal tube, chiefly from the cut ends of the bone; but it is a much slower process. When the periosteum is excluded, union by callus still occurs, but the field of repair, being shut out from the vascular supply of the periosteum, produces its callus slowly and in small quantities.

As every fragment in a comminuted fracture is a focus of repair, it follows that every fragment ought to be retained, in the interests of quick and firm union. But where mobility rather than strength is required, as in the neighbourhood of a joint, it will often be better to remove loose fragments, lest excessive callus cause joint fixation. Any direct operative attack upon a comminuted fracture will involve the risk of interfering with the vitality of the fragments, and therefore lessening their ability to act as centres of repair.

Indirect Fixation of the Femur.—The method of indirect fixation by transfixion of the bone, which is so excellent in the case of the tibia, cannot be applied without modification to the upper part of either limb, because in both cases the upper portion of the bones (humerus and femur) cannot be transfixed, or rather a transfixing-pin cannot be brought to the surface, because in the one case it would lie in the axilla, and in the other in the perineum.

I thought to solve this difficulty by unilateral transfixion. Two screws were passed into and through the femur, one just below the trochanters and one just above the condyles. Each was provided with a rim or shoulder which held firmly against the bone surface when the screw was driven home tightly. After dividing the bone between the screws, the soft parts were united, and the ends of the screws left protruding beyond the skin. These were then fixed to a steel bar by nuts (*Table XIV*, p. 171).

Much to my surprise, all four of these experiments failed to give a satisfactory result. That is to say, in three out of four one screw came out of the bone and gross deformity resulted, and in the only one in which the apparatus remained in place very considerable angulation occurred. In two cases the screws were fixed at a slightly divergent angle to the longitudinal bar, so that the tension of the muscles should tend rather to pull the bones more firmly on to the screws; but the result was no better.

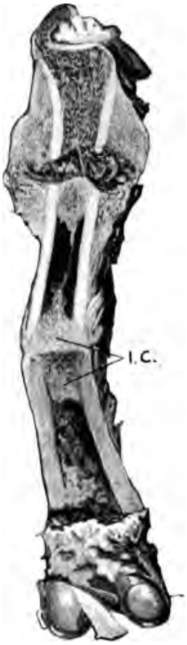


Fig. 76.—Cat's femur (No. 82), 42 days after operation. Treated by unilateral screw fixation. There is much angulation, and great thickening round the upper screw-hole. I.C, Internal callus.

These screws were one-eighth inch in diameter, with a stout thread, and yet within much less time than is occupied in consolidation of the bone, they generally worked loose. This is in accordance with what has been stated above as to the reaction of metal screws tightly driven into hard bones.

Fig. 76 is from experiment No. 82, a cat's femur forty-two days after operation. There is a marked angulation in a posterior direction, with much callus thickening round the upper screw-hole. Natural callus is well developed, but union is not yet osseous.

Regeneration of Bone after Subperiosteal Removal of a Piece of its Entire Thickness (*Table XV*, p. 172).—The transfixion apparatus having proved itself such an excellent device for studying the repair of simple and comminuted fractures, it seemed a good method for observing the repair which occurs when a piece of the entire thickness of the bone is removed.

In all cases the cat's left tibia was the subject of the experiment, and a section of the bone, about half an inch in length, was removed subperiosteally by means of two saw-cuts. There were five experiments in this group ; in the first three the cut ends of the bone were left bare ; in the last two they were covered in thin rubber, tied on with a fine wire.

Fig. 77 *a* is from No. 80, fourteen days after the operation. There is seen a healthy and fairly vigorous formation of internal callus from the upper fragment, and much less from the lower. Otherwise there is no trace of any callus or reparative material between the bone ends. The callus mass growing from the upper fragment is very sharply defined, and gives the impression of merely forming a cap for the bone end, rather than a bridge that is going to stretch across the gap.

In *Fig.* 77 *b* is seen No. 79, thirty-five days after operation, and here too there is a perfectly clear interval between the cut ends of the tibia, with no suggestion of new bone or callus. In this case the fibula has fractured, and the exuberant callus formed round the broken ends of the fibula would have been more than enough to fill the gap in the tibia. Thus there is a striking example of the absence of callus when bone ends are not in contact, and the exuberance of callus formed by broken bone ends which are allowed some movement against each other.

In the three cases Nos. 79, 80, and 83 there was no trace of callus being laid down by the periosteum, and much less pouring out of callus from the cut bone ends than I expected. In the

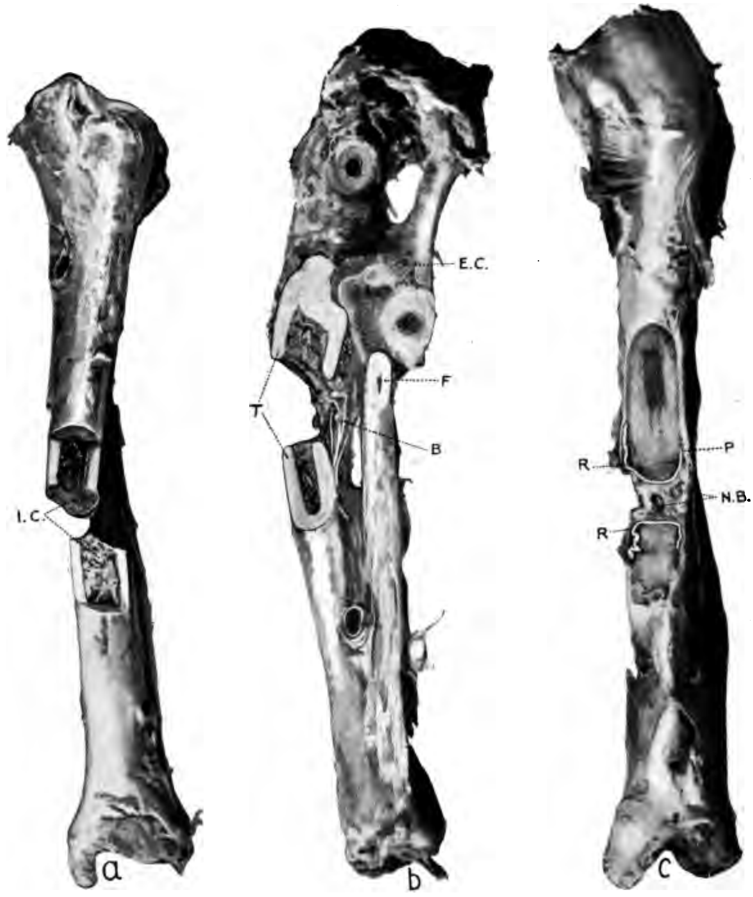


Fig. 77.—Cats' Tibias after Subperiosteal Removal of a Piece of the Shaft in its Whole Thickness.

(*a*). No. 80, after 14 days. Internal callus best developed in upper fragment. Nothing in gap. I.C. Internal callus.

(*b*). No. 79, after 35 days. Fibula has broken. In the tibial gap there is no new bone, but round the fibular ends there is a big mass of new bone. T, Tibial ends. F, Fibula. E. C, External callus. B. Bridge of soft tissues only in the gap between bone ends.

(*c*). No. 85, after 42 days. The ends of the bone have been covered in by rubber tissue ; but in spite of this the gap is filled by callus, both cartilage and bone, derived from the periosteum. P, Periosteum. R, Rubber tissue. N. B, New bone in the cartilaginous callus mass.

two cases Nos. 84 and 85, I wished to eliminate this last factor; for this purpose a small fragment of rubber tissue from a glove was tied over the cut ends of the bone. In both these there was found perfectly normal internal callus formation beneath the rubber tissue, proving that such callus is derived from the bone and its marrow cavity, and not from the periosteum. In No. 85, however, a surprise was in store. The specimen is illustrated both by skiagram and by drawing (*Figs.* 79 and 77 *c*). There is here unquestionably an advanced callus formation between the rubber-covered bone ends and the periosteal sheath. This is chiefly cartilaginous, but there is a well-marked bone nodule in its centre, which is dense enough to show in the skiagram. It is impossible to avoid the conclusion that in this case, at any rate, the periosteum has laid down the new bone.

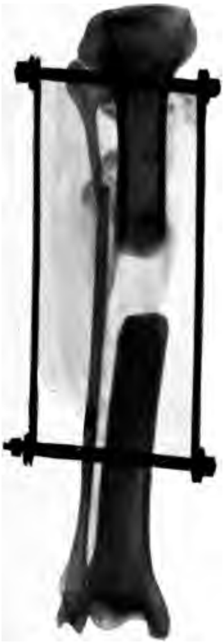


Fig. 78.—Cat's tibia (No. 79). Skiagram of specimen shown in *Fig.* 77 *b*. There is complete absence of bone in the gap after 35 days.

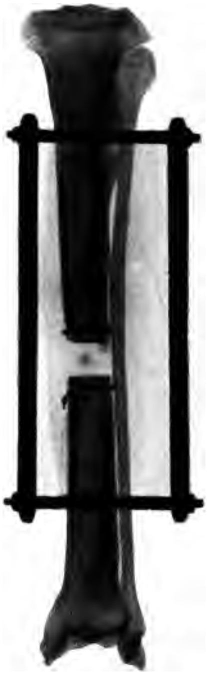


Fig. 79.—Cat's tibia (No. 85). Skiagram of specimen shown in *Fig.* 77 *c*. Two nodules of bone are seen in the gap.

Regeneration of Bone when a Part only of the Thickness has been Removed. (*Table XVI.* p. 173).—These four experiments were undertaken in connection with the subject of bone transplantation, which cannot be discussed in any detail here. The skiagrams are shown merely to illustrate the rapid repair which takes place under the above conditions. The anterior border of the tibia was exposed, and a piece 1 in. long sawn from the bone, so as to remove about half its entire thickness. This piece was then split into two equal parts, and one was grafted whole, and the other after minute subdivisions, under the fascia lata of the thigh. In all cases the grafts lived.

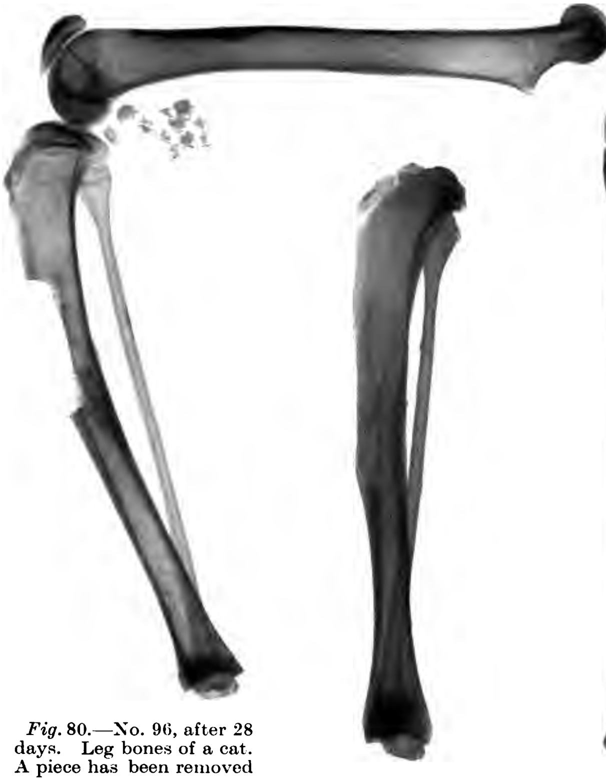


Fig. 80.—No. 96, after 28 days. Leg bones of a cat. A piece has been removed from the tibia, and grafted in two parts in the thigh —a single piece and a number of chips.

Fig. 81.—No. 94, showing regeneration of cat's tibia after 60 days.

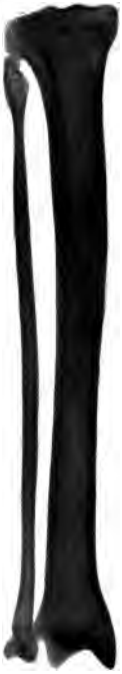


Fig. 82.—No. 91, showing regeneration of tibia after 63 days.

The whole graft seemed to remain unchanged, whilst the comminuted graft formed a bone mass of some size.

Figs. 80, 81, and 82 show the tibia after intervals of twenty-eight, sixty, and sixty-three days, and in the last two it will be seen how completely the gap in the tibia has been replaced.

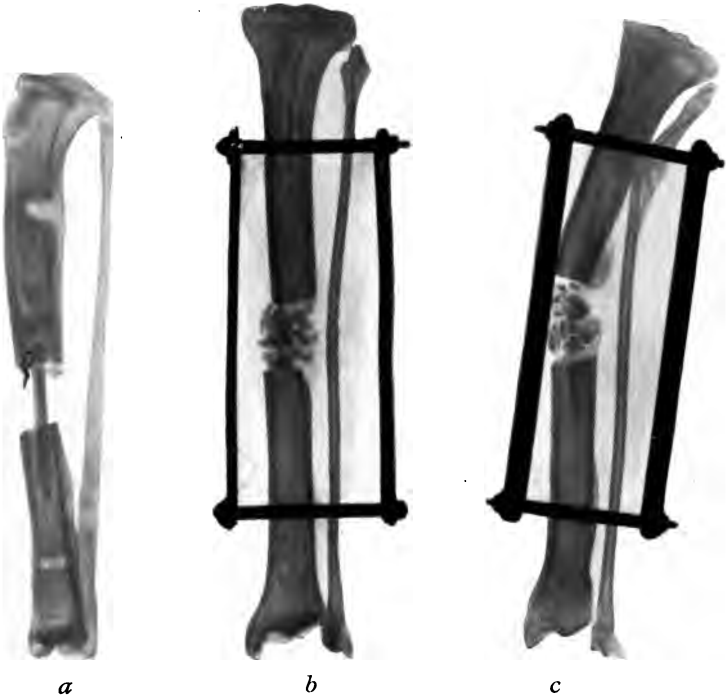


Fig. 83.—SKIAGRAMS OF CATS' TIBIAS, WITH FRAGMENTS GRAFTED.

(*a*). No. 86, after 49 days. Single graft in the form of an intramedullary peg.
(*b*). No. 88, after 15 days, showing separate fragments.
(*c*). No. 89, after 70 days. The chips are still quite discrete.

Experiments in Filling a Bone Defect by a Single Large Piece or by many Small Chips. (*Table XVII*, p. 173.)—These experiments are as yet only three in number, and so not very conclusive, but they are interesting as far as they go. In all, the leg was put up in the transfixion apparatus. In the first, the gap in the tibia was made good by a rod cut from the opposite leg bone and thrust into the marrow cavity of both bone ends. After forty-nine days the specimen (*Figs.* 83 *a* and 84 *a*) shows a good solid union. The bone as a whole gives a feeling of perfect solidity. The graft is embedded in callus which is chiefly cartilaginous, and there is certainly a structural continuity between this callus and the graft. Whether the callus has grown from, or merely grown into, the graft is impossible to say. *Figs.* 83 *b* and *c* and 84 *b* and *c*, illustrate the two specimens

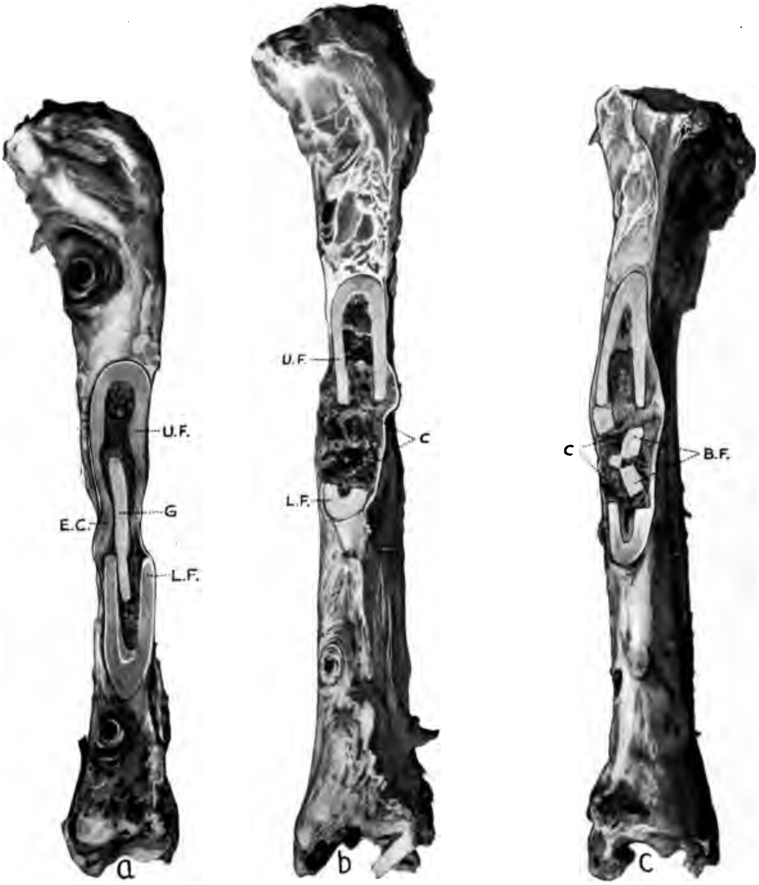


Fig. 84.—Same Specimens as in *Fig.* 83.

(*a*). No. 86, after 49 days. A graft from the opposite leg lies firmly growing into the ends of the bone and surrounded by a cartilaginous callus. U.F, Upper fragment. L.F, Lower fragment. E.C, External callus. G, Bone graft.

(*b*). No. 88, after 15 days, the grafted bone chips lying embedded in early callus. U.F, Upper fragment. L.F, Lower fragment. C, Callus with loose bone chips.

(*c*). No. 89, after 70 days. Except that the callus is cartilaginous, there is not much advance over the previous specimen, many of the chips being still quite distinct. C, Callus. B.F, Bone fragments.

in which a piece of the tibia was cut out and then replaced after crushing up into small pieces. The skiagrams are remarkable for the great similarity between (*b*) after only fifteen days, and (*c*) after seventy days. Both the drawings show that the particles of bone are embedded in callus; but in neither case is any solidity attained. In (*b*) the callus is only cellular, in (*c*) it is partly cartilaginous. The manner in which some of the particles remain clean-cut and apparently inert forms a very sharp contrast to the results where the bone was merely crushed but the particles were not removed from their bed (*Fig.* 71, *b* and *c*).

GENERAL DEDUCTIONS BASED UPON THE ABOVE EXPERIMENTS.

It now remains to examine as a whole the series of facts above recorded, and to discuss their bearing upon the practical problems of the operative treatment of fractures and the theory of bone repair. The task of applying these deductions to the practice of clinical surgery I shall take up in a later chapter, being content here with inferential or occasional references to human fractures.

It seems necessary, however, to point out the chief conditions in which animal fracture experiments fail to represent the conditions found in the human subject. Perhaps the most important of these is the fact that there is no interval between the infliction of the injury and the operation undertaken for its repair. Thus the overcoming of the contraction of the muscles and the difficult problem of the arrangement of the fragments in a natural position are not dealt with. The use of external splints and bandages is impracticable, and the co-operation of the patient, apart from the mere instinct of resting a painful limb, is not available. The animals, being quadrupeds, can more readily move the limb without bearing weight upon it than is the case when the leg of a biped is injured.

I was not allowed, by my licence, to break the bones, and therefore the experiments are only concerned with clean-cut bone division, and not with the jagged injuries of natural fractures. And lastly, the longest time of observation in any of my experiments was seventy-one days, so that the remote results of the operative treatment cannot be estimated from them.

I.—Factors Determining the Success of Direct Operative Treatment of Closed Fractures.

(*a*). *The Permanent Burying of Foreign Bodies.*—There are many to whom this appeals as the chief factor in the situation.

Rather than bury foreign bodies of an unabsorbable nature, they would submit the patient to almost certain anatomical and functional mal-union, or avoid these by methods involving the most tedious delay. Is it possible to determine experimentally whether there is any foundation for these fears of the foreign body in the treatment of fracture? As far as the evidence goes, and for the comparatively short periods of observation, these experiments show that indifferent aseptic foreign bodies do no harm. My justification for this statement is as follows. If a foreign body be harmful, then the more foreign body the greater the harm. But all the experiments with the long steel plates and pins (see *Figs.* 52, 53), and all those with steel intramedullary pegs, in which, relative to the bones, a very large mass of metal was used, were successful anatomically and functionally, and in none was there evidence of injury to the tissues. In all the cases where only a small quantity of foreign body was buried, viz., the short plates, small screws, wire, etc., there was evidence of anatomical and functional failure, and in most of them there was grave tissue inflammation or suppuration. Of course, the good result from the big plates and the bad result from the small are due to the fact that one is mechanically efficient and the other is not; but the fact that the best results were obtained in those cases where the largest foreign bodies were used, is significant of the tolerance of the tissues.

Another circumstance pointing to the same conclusion is that, in many cases when short plates were used, the plate remained firmly fixed to one fragment after disunion of the other end had taken place and after the parts had come to rest (see *Figs.* 43, 44, 45, 46). In such cases, if there were always an effort on the part of the tissues to cast off the foreign body, all the screws would certainly be loose after four to six weeks.

(*b*). *Mechanical Efficiency of Fixation.*—This is the most important factor necessary for success. Long plates and perforating pins, or intermedullary pegs of a strong material, gave almost uniform success. Any method of fixation which left a weak and shaky junction was always a failure. Bone has the physical properties of neither wood nor metal. It will not allow a screw to bury its thread in its substance; neither will it maintain for long a thread that has been tapped into its substance if the surface of this thread is subject to continuous tension. Hence it is that any method which depends chiefly upon the bite of a screw into the bone is mechanically inefficient. It is the same principle as that of the tightly-tied ligature in the soft parts, which quickly cuts its way through them until tension is relieved.

It has been widely held that no fixation of the bones in the treatment of fractures is necessary at all. The further assumption has naturally followed that the object of operative interference will be attained if the minimum of fixation is carried out. A strand of wire, one or two staples, or a short plate and a few screws which for the moment hold the bone ends together, are regarded as doing all that is necessary. This assumption is a fallacy. Healing can only take place when the tissue tension has reached stable equilibrium. If no operation be performed, the parts soon adjust themselves so that tension is at an end, and in this position union takes place. When a mechanically efficient fixation of the bones has been made, all the muscular force of the limb or the effects of gravity or leverage cannot move them; hence, here again there is nothing to delay healing. But if the bones are tied together by anything which does not hold them firmly and strongly, then movement will constantly take place, and muscular tension will ever be acting upon the healing tissues instead of being borne by the fixation apparatus.

The relatively great force which fixation apparatus has to withstand is shown very well by the experiments with ivory and bone pegs, in every one of which the peg was snapped across.

To leave the parts alone to adjust themselves by natural laws, and to fix the parts mechanically so that they can withstand all the possible strain that can be put on them, are both reasonable methods; but to tie the parts together loosely or weakly is a fatal compromise which is much worse than either.

Bones left to natural repair will, after finding tension equilibrium, heal by granulation. Bones firmly and accurately fixed will heal by first intention. Bones weakly joined by a method which allows more and more movement between them will not join at all, or their junction will be long delayed.

(*c*). *Sepsis: Its Origin and Significance.*—The attainment of asepsis has quite rightly been laid down as a *sine qua non* in the operative treatment of closed fractures; but the difficulty of its attainment has probably been misunderstood. It has been generally assumed that when metal structures, e.g., plates, screws, or wire, lie at the bottom of a septic sinus, this complication is due to some technical error, infective material having been implanted in the wound at operation. But I think there is another explanation of the matter. In the above experiments, exactly the same technique was used in the same place and the same circumstances throughout. And yet in one series, e.g., the short plates and screws, or the bone and absorbable pegs, there was a very high proportion of sepsis; whilst in another, e.g., the long plates or the steel pegs, there was not one infected case. This cannot be explained by one group all being done at the same time, because for the most part varied experiments were done on the same day. It seems to me there are three circumstances which conduce to sepsis, quite apart from errors in the aseptic technique of the operation; (1) the mobility of the foreign body used and of the bone fragments; (2) the superficial position of the foreign body; (3) the action of an irritant foreign body upon the tissues. Contrast, for example, the following groups of cases :—

Cases where there is much Mobility	Number of Experiments	Number of Septic Cases	
Short plates and screws	9	4	
Bone pegs	7	3	
Spiral wire pegs	6	5	
Total	22	12	(more than half)
Cases where there was no Mobility			
Long plates and transfixing pins	5	0	
Steel pegs	7	0	
Total	12	0	(none)

Then, as regards the position of the fixing structure. This is much more likely to cause sepsis if it is superficial, e.g., in the tibia, than when deeply buried in the thigh. Thus, in the above-mentioned twelve septic cases, ten were tibias and only two femurs. The influence of a chemically-irritant foreign body is seen in the action of magnesium. In the pegging operations with this substance there were four septic cases in six operations.

These facts prove that sepsis must depend on something other than errors in the operative aseptic technique. That entire series of operations can be done without a single septic case must be evidence that the technique is good; and when a high proportion of sepsis arises, this is probably post-operative in origin. The mobility of the fragments, together with a loose foreign body, cause a great outpouring of fluid round the fracture. This fluid will soon find its way through the recently sutured wound, and especially so if the loose body lies just underneath the skin (*Figs.* 43 and 46). The escape of this fluid opens the wound and forms a sinus, which quickly becomes infected from the skin surface. This is a reasonable explanation of the occurrence of sepsis in so large a proportion of cases where there is mobility, a superficial position of the mended bone, or an irritating foreign body. In other words, in the majority of cases sepsis is the result of faulty fixation, and not its cause.

(*d*). *Delayed Union.*—There is a good deal of clinical evidence to show that the operative treatment of fractures is accompanied by delay in union. But in this simple problem there are really many factors. Only to mention one of these: probably many cases are treated in such a way that the materials used for fixation, whether screws or wires, become loose in the manner already spoken of. In such a case repair can hardly begin until the parts have acquired a position of equilibrium; and as the tension of the muscles slowly overcomes the artificial fixation, the bone ends gradually slip over one another until a stable position is assumed. Naturally all this will delay union, and much more so if the process of undoing the fixation leads to suppuration in the way described in the last section.

No cases should be included, therefore, in which fixation was mechanically inefficient, because in these we can never be sure whether a particular result is due to the fixation or to its failure. Of my cases of simple closed fracture with immovable fixation, two series only are suitable for the consideration of this question, those with long plates and transfixing-pins, and those with steel intramedullary pegs. In each of these series there is one case in which, after the lapse of a relatively long time, there was no appearance of union (No. 52, cat's tibia, *Fig.* 53 *d*, 42 days after operation, long plate and split pins; perfect wound healing, and good position and function. No. 50, cat's tibia, steel peg, 42 days; good position, healing by first intention, and excellent function). So that in these series, including twelve cases altogether, two show delayed union apart from any other complication. This is positive evidence supporting the contention that operative fixation causes delay in union.

It is most difficult to go further than this, and explain why these exceptional cases occur. If it was the absolute fixation preventing the bone ends rubbing upon one another, then it would surely occur more often than once in five times with the long plates and split pins.

Bier and his school have suggested that it is the hæmostasis and the clearing out of blood-clot which in operative treatment of fractures causes delay in union; but in my experiments the fractures were quite fresh, and there were no blood-vessels tied or constricting bandages applied, so that there must always have been blood surrounding the fracture.

The most probable explanation that occurs to me is the mere interference with the blood-supply of the fractured bone ends. In the shaft of a long bone there are three sets of vessels: those in the periosteum, the medulla, and the Haversian canal system. When any operation is performed on these parts, there is the probability that the periosteum is raised from the bone, which will temporarily divert the first set; and if the marrow cavity is extensively bored, then the second set will also be more or less destroyed. Thus there will be left only the third, that is, the small vessels in the dense bone itself. It is easy to understand that under these circumstances the blood-supply will be so poor that there will be a delay in healing. In both the specimens I have referred to this explanation would be satisfactory. The bone ends are perfectly healthy, but merely indolent.

There then arises the further question as to the ultimate result of this delayed union. If the bones are firmly fixed by prostheses which actually take the place of either internal or external callus, the result from a practical point of view is negligible. That is to say, the function of the limb is just as good in every way as if union of the bones had occurred, and in a further period of time the indolent bone ends will grow together. This line of argument supplies another reason for making the union mechanically firm, and of such a character that it will support the bone in good position for an indefinite time.

(*e*). *Comparison of Periosteal and Intramedullary Methods of Fixation.*—For this purpose, we have again the same two series of cases for consideration, viz., those in which long plates with transfixing-pins, and those in which steel intramedullary pegs, were used. Practically, these two groups have both given the same results—a firm lasting fixation, good union in the majority of cases, an absence of sepsis, and uniformly good function. In both there has been one case of delayed union.

The advantages of the long plates with transfixion are that their application interferes but little with the marrow cavity, and that they can be removed if necessary without disturbing the bone union. On the other hand, they are more difficult to apply accurately if there is much displacement of the bone, and they require a long incision, with an exposure of the bone on two opposite sides.

The advantages of the pegs are that with the proper instruments they are easier to apply than plates, and will require only a small incision, and that when applied, they automatically ensure the correct alinement of the bone. But for general use there are many drawbacks. They require an extensive sacrifice of the medullary cavity, and a large series of different-sized pegs and borers; they cannot be used if the bone is at all splintered or comminuted; and they cannot be removed without danger of re-fracturing the bone.

II.—On the Indirect Methods of Fixing the Bone.

In my experiments, these have only been represented by the double transfixion apparatus. By the use of this I have obtained better results than with any method of direct operative attack upon the area of fracture. That is to say, in every case there was rapid union, perfect function, and absence of sepsis (apart from cases where plates were also inserted); and further, the method is as readily applicable to comminuted and open, as to simple and closed, fractures.

I think my experiments bear this out so amply that I need spend no more words in enforcing it, beyond pointing out that the method is much easier of application than any other. In fact, it only constitutes a minor surgical proceeding, which can be carried out in a few minutes with a very simple technique and the minimum risk of sepsis.

The question of real moment about this method is how far the experimental conditions are representative of those occurring in actual fractures. In the experiment the transfixing-pins are applied before the bone is divided, and thus anatomical accuracy ensured. This is the crux of the whole matter. Any method which lays hold of the two bone ends in such a way as to restore good anatomical position and maintain it until union has occurred, without interfering with the function of the joints and muscles, may be regarded as fulfilling the conditions of these experiments, and may be expected to give equally good results. In some cases, simple extension by weights, springs, or screws, applied by apparatus which acts only through the unbroken skin, will do this. In others, some sort of transfixion of the bone ends will be necessary, in order both to overcome the muscle tension, and to maintain this without immobilizing the limb. But in many cases, any of these methods will fail in attaining the experimental conditions, either because they do not accurately reduce the fractured ends, or because they fail to retain the broken bone firmly, or because in doing these things they require the long immobilization of the muscles and joints.

III.—The Treatment of Comminuted Fractures.

The success of the method of indirect fixation is nowhere shown to greater advantage than in the comminuted cases. In the experiments I have related, the bones were not merely divided into several parts, but they were crushed so as to be reduced to many small pieces. In any given case where there are only a few large fragments, these may of course be united severally to one another and to the main parts of the bone. But the cardinal principle of mechanically efficient fixation will be in danger of violation in direct proportion to the complexity of the fracture. On the other hand, by securing the main fragments in correct position and fixing them to one another, and by leaving the small fragments as little disturbed as possible, the best possible result may be obtained. This principle can be carried out either by the transfixing-pins with outside connecting-bars, or else by long plates applied on each side of the bone, bridging the comminuted portion, and connected to one another by bolts which pierce the whole thickness of the shaft.

To ensure rapid and strong union, every fragment is to be left in position, quite regardless of whether it has a periosteal attachment or not. But in cases where the strength of the bone is not of such importance as the mobility of a neighbouring joint, it is wise to remove some of the loose fragments of bone in order to avoid callus excess. If any part of the bone is removed, then broken up and put back in place, these ill-fitting bone chips are apt to take on osteogenetic function very slowly (see *Figs.* 83 and 84 *b* and *c*) ; therefore even the temporary removal of pieces of bone and a return of these in a disorderly manner is to be deprecated. The reason for this will be alluded to in a later section.

IV.—The Treatment of Open Fractures.

In the strict sense of the word all my cases were open fractures ; but in the ordinary clinical sense none of them were such, except those where the wound broke open subsequent to the operation. Open fractures in the usual sense of the term must all be regarded as septic ; but practically they are divisible into those where the infection is so trivial that no serious delay is occasioned by the wound, which quickly closes and then allows operative treatment to be carried out, and those where the infection is of a serious character, dominating the case.

My experiments have no practical bearing on the latter group ; but as regards the former, which are much the most numerous, they give some useful suggestions. In such cases, clearly some indirect method of fixation should always be adopted without delay. In many this will be all that is necessary, and in others it will suffice to minimize displacement until the wound has healed and direct operative attack can be undertaken. What I have written in the last sections about the indirect method of bone fixation applies with great force to these cases of open fracture ; and there is this fact in addition : with the transfixion or other similar apparatus, the wound can be dressed without disturbing the fracture, and owing to the whole of the surface of the limb being left uncovered, any extension of septic mischief can be detected and dealt with as it arises.

ON THE REGENERATION OF BONE AND THE THEORIES OF CALLUS FORMATION.

It would require a large treatise to discuss adequately all that has been done and written on this subject, and I propose to content myself with a very brief statement of some of the main matters of dispute, pointing out the bearing that the facts of my experiments have upon them. For the reasons both of brevity and simplicity, I have referred but little to microscopical appearance ; for although parts of the bones from all the important specimens have been decalcified, embedded in paraffin, and cut in serial sections, the description of these would take me far beyond the scope and purpose of this book.

The Parts played by Periosteum and Dense Bone in the Process of Regeneration and Repair.—The teaching on this subject, of which Ollier has been the most distinguished author, and which has dominated the conceptions of surgeons, pathologists, and students, has been that the periosteum is the all-important factor in bone growth. It has been proved by Ollier and many others that the separated periosteum can and does reproduce bone under certain conditions, particularly in young subjects and when the periosteum is left partly attached to its original bed. There is a negative side to this evidence which has been rather overlooked, the practical importance of which, however, is very great; that is to say, many, in fact most, experiments on the transplantation of periosteum have had no result. This has been assumed to be due to some technical error or experimental accident, and the positive results have been held to outweigh the negative. The fact that periosteum can and does sometimes reproduce bone being taken as proved, many experiments have been cited in which all new bone formation connected with the periosteum has been regarded as derived from the latter—for example, the well-known silver ring experiment, in which a metal band laid round a bone under the periosteum is covered over in time by new bone between the metal and the periosteum; the fallacy of this deduction lies in the fact that in this and in all similar experiments it is obvious that the new bone may be derived from the old bone, and merely grow thence under the periosteal envelope.

Macewen's experiments on the other hand, have proved that the living bone is the main origin both of regeneration and repair, and that these can take place in the absence of the periosteum. He entirely denies the osteogenetic faculty of the periosteum, and points out that whereas bone growth is only occasional and exceptional from periosteum completely separated from the underlying bone, bone growth from living bone deprived of its periosteum is, on the other hand, regular and constant. It is evident, as I have said, that in the examination of fractured bones—apart from special devices to separate the periosteum from the bone—it is impossible to be certain whether a given mass of external callus is derived from the periosteum which is on one side or the bone which is on the other (see, for example, the specimens in *Fig.* 66), and it is rather astonishing that so many observers have attributed the origin of external callus to the overlying periosteum, without considering that it may equally well have grown out from the underlying bone. But even with such simple specimens of external callus, the appearances support much rather the osseous than the periosteal origin thereof. *Fig.* 85 gives a good illustration of this; and the specimens shown in *Figs.* 47, 49, and 60 *a* go a step further, for in all these it is seen, even with the naked eye, that the callus is formed both of bone and cartilage. The process

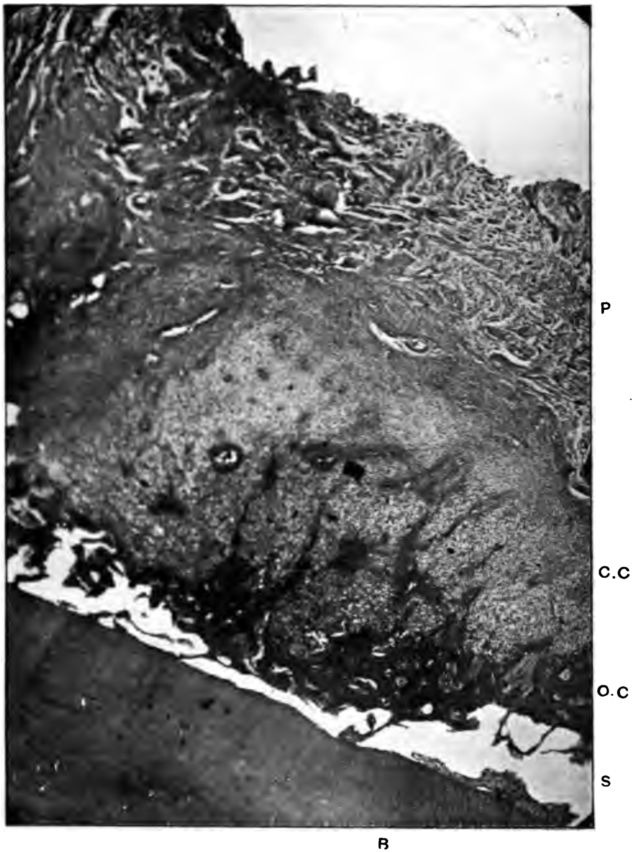


Fig. 85.—Cat's Tibia (No. 5), the whole Specimen being shown in *Fig.* 58 *a*, 17 days after Operation.

Longitudinal section of the dense bone, with the overlying external callus, as seen under a ½-in. objective.

B, Dense bone of the shaft. **S**, Space between the callus and the dense bone, artificially produced in the cutting of the section. **O.C**, Deep layer of ossified callus. **C.C**, Outer layer of cartilaginous callus. **P**, Periosteum fused with overlying connective tissue.

There can be no doubt that this thick layer of external callus is growing in direct continuity with the bone, and the ossification proceeding from the bone. The way in which the callus breaks from the bone in the process of cutting the section, although purely accidental, is nevertheless very instructive, because it marks the line of most ready cleavage, between two layers of tissue of different density. When necrosis occurs, it is in this line of cleavage that the inflammatory products accumulate and separate the outer involucrum from the inner sequestrum. But, nevertheless, the involucrum has grown from the bone.

of repair consists in the cartilage being converted into bone, and this process of ossification can be seen to proceed from the surface of the bone outwards towards the periosteum, and not in the reverse direction. When the periosteum has been excluded by the use of encircling metal plates, the formation of callus by the bone itself is demonstrated to take place without fail. In *Fig.* 56 *a* the bone is seen, after ten days, rough and pitted by granulation tissue, which is the first stage of callus. In *Fig.* 56 *b* the external callus is well advanced. In *Fig.* 57, after fifty-two days, the bones are seen to be united by a thin layer of external callus, the amount of which has been limited by the steel plate, and a thin transverse disc of cartilage at the line of fracture; the interior of the bone is occupied by a large mass of internal callus; this can only have originated from the marrow cavity and from the dense bone, which has almost disappeared in giving rise to this new tissue. *Figs.* 75 *a* and *b* show the same thing in comminuted fractures.

In the next place, we have a series of cases where a piece of bone has been removed from the shaft, leaving the periosteum in its place. Some of these were comminuted fractures, and in others a piece of bone was cleanly cut out. In the former there was a uniform filling up of the gap by callus of a very immature character. In the latter there was no callus formation except at the ends of the cut bone. In all these cases the space left is bounded both by the sleeve of periosteum and by the cut or broken bone ends, and therefore either of these structures may take part in filling it. *Figs.* 72 and 73 show the crushed bones. In all four specimens the gap is filled with callus; in *Figs.* 72 *a*, 72 *b*, and 73 *a*, there is more, or more advanced, callus next to the bones than in the centre—evidence that these bones have produced the callus. In *Fig.* 72 *a* the central point is merely fibrous, whereas at either end it is ossified. In *Fig.* 72 *b* the central part is cartilage, whilst the part in contact with the bones is bony. This is seen in greater detail in the sections shown in *Fig.* 86, *A* and *B*.

Figs. 77 *a* and *b* and 78 (Nos. 80 and 79) show the result of cutting out a part of the bone and leaving the periosteum. There is a complete absence of any callus in the greater part of the gap left. *Fig.* 77 *a* (No. 80) shows a cap of callus upon the cut bone end, sharply limited, and looking as if it was unlikely to have spread much further if the animal had been left alive. The only difference between these cases and those of

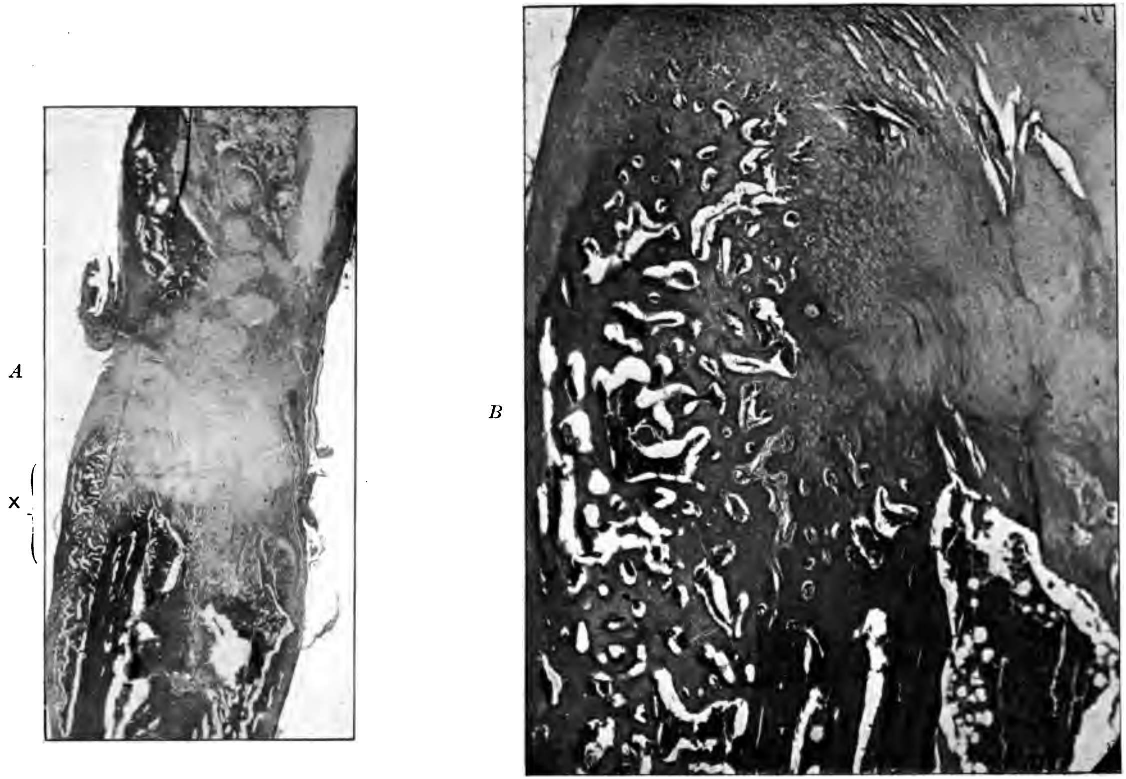


Fig. 86.—No. 70, AFTER 42 DAYS, LONGITUDINAL SECTION OF THE SPECIMEN SHOWN IN FIG. 72 *b*.

A.—Magnification by ½-in. objective. X is the portion of bone shown in *B*. At the upper and lower parts are seen the ends of the bone, and between them the new callus. This is cartilaginous in the centre, but from the bones osseous tissue is growing into it.

B.—Magnification by ¼-in. objective. The direct structural continuity between the bone and the ossified callus is seen.

the comminuted fractures was that in one case the bone was clean-cut and in the other crushed. In both the periosteum was similarly treated. The crushed bones, having a larger broken surface, exude more callus, and the cut bones less, and in none of these particular specimens is there any evidence of the periosteum taking any important part in the regeneration of bone. In two cases, not only was a part of the bone removed, but the cut bone ends were covered by rubber tissue in order to exclude them from a share in the formation of any tissue that filled the gap. In one (No. 84) there was nothing in the gap; but in the other (No. 85), shown in *Figs.* 77 *c* and 79, there was quite good callus formation. Such a specimen as this, taken by itself, might be put forward as a convincing proof that the periosteum, and periosteum only, is the source and origin of callus; but taken in conjunction with all the other evidence in this paper, it is merely an example of the fact, incontestably proved by Ollier and others, that under certain conditions the periosteum can and does reproduce bone. It in no way shakes the evidence that, under usual conditions, new bone and bone repair originate by proliferation from bone tissue, in which process the periosteum plays quite a secondary part.

Between the fibrous periosteum and the bone there lies a layer of cells which are nothing more or less than a layer of osteoblasts. If in separating the periosteum from the bone this layer of osteoblasts be taken with it, as will usually be the case in young bones or after inflammatory changes have occurred (see *Fig.* 85), when the layer is thick, then the separate periosteum has osteogenetic power in virtue of the bone layer which adheres to it. But the removal of this osteoblast layer with the periosteum is more or less accidental, and hence the great uncertainty of reproducing bone by a transplantation of periosteum. On the other hand the bone itself is full of osteoblasts, and when any portion of it is removed without interfering with its vitality, it will always be capable of reproducing new bone. If the term periosteum is applied, as it ought to be, simply to the fibro-elastic tissue layer, then it may be held that this is nothing more than a limiting membrane without any osteogenetic power. But if by periosteum is meant the fibrous layer with the bone-cells adhering to its deep surface, then it has osteogenetic power just in proportion as it takes with it this part of the living bone. The observation has often been made, but its significance in this connection rather overlooked, that whatever doubt and uncertainty there may be as to whether the periosteum can and does reproduce bone, there is no doubt whatever that the bone can and does always reproduce periosteum when a part of the membrane has been removed from its surface. If then the bone is certainly the mother of the periosteum, it is very unlikely that the periosteum is also the mother of the bone.

The Amount, Position, and Constitution of Callus.—Callus, as the chief material of bone repair, is laid down in an amount which differs according to certain well-defined conditions. In the case of the soft tissues, the healing of a wound is said to be by first intention when the severed tissues seem to grow directly together with the minimum of cementing new tissue; and by granulation where there is a large gap to be filled, and the original tissues are eventually united by a large mass of scar tissue. So it is with broken bones. When the fractured surfaces are placed in accurate apposition and firmly held in

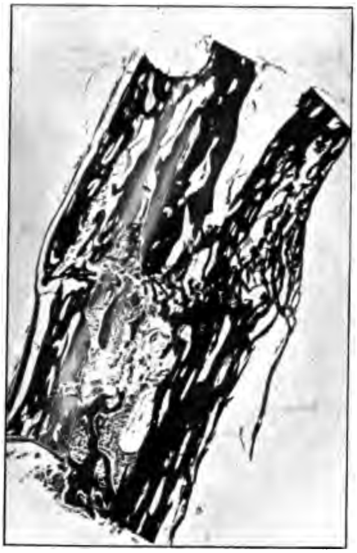


Fig. 87.—LONGITUDINAL SECTION OF THE SITE OF FRACTURE IN NO. 53. ½-IN. OBJECTIVE. The same specimen as that shown in *Fig.* 53 *c*, after 42 days. The section passes through the side of the bone, the marrow cavity not being fully shown. Note the great thickening of the dense bone and its extensive canalization. The fracture is seen to be merely a linear irregularity, and there is practically no callus.

that position, as seen in ***Figs.*** **53** *a* and *c*, **65** *a* and *c*, **69** *b*, **70** *a*, *b*, and *c*, there is the very minimum of reparative callus, and a direct continuity of the bones is re-established. This is shown in microscopical section in ***Fig.*** **87**. A consideration of the experiments makes it difficult to believe that any such result could be obtained in complete fractures when the bone ends are not accurately apposed, or when they are allowed free movement.

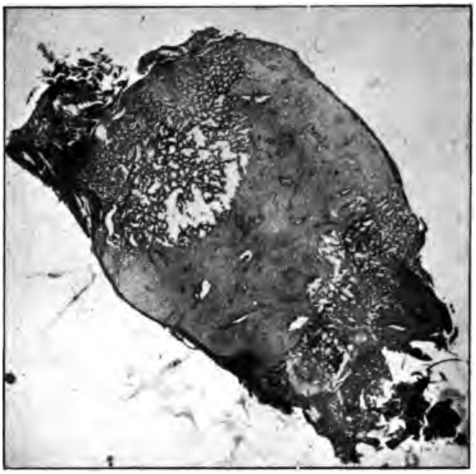
On the other hand, there is a great callus excess produced by mal-position and mobility (***Figs.*** **43, 45, 47, 48, 49, 60** *a*), or by a degree of mobility without mal-position (***Figs.*** **65** *b*, **66** *a* and *b*), or by any condition of tissue irritation (***Figs.*** **63** *a* and *b*, **66** *a* and *b*), or by great fragmentation of the bone (***Figs.*** **65** *c*, **71** *b* and *c*). These facts are so generally conceded that it is not necessary to do more than illustrate them by the examples given.

The opposite extreme, the failure of callus formation, with consequently delayed union, is seen in ***Figs.*** **53** *d*, **60** *b*, and ***Specimen*** **52** (not illustrated), and I have discussed the explanation of this phenomenon above in connection with the factors relating to operative treatment. I would merely repeat here that this seems to be due to an interference with the blood-supply of the bone ends by a simultaneous interference with the periosteum and medulla. Such specimens as that in ***Fig.*** **60** *b*, and others in the same series, are susceptible of a further explanation. An oblique fracture is surrounded by several turns of wire. This is not enough to hold the bones rigid, and there must therefore be a tendency to mechanical destruction of external callus exuding from the bones by the chafing wire.

The formation of a false joint, illustrated by ***Figs.*** **50, 51, 301** *a*, and **301** *b*, has always been associated in my experiments with great displacement of the fragments and unrestrained mobility. In the specimens shown in ***Figs.*** **50** and **51** there is little or no callus, but in ***Figs.*** **59** *a* and *b* are seen cases where pseudarthrosis co-exists with callus excess.

The occurrence of cartilage in callus is a matter which has given rise to much discussion. That it is a constant feature of the repair of animal fractures has always been recognized. It is present in relatively large amounts when the callus mass itself is great, i.e., when displacement and mobility co-exist. This is well illustrated in ***Fig.*** **60** *a*. It persists longer and in greater amount at the line of fracture and under the periosteum

A



B

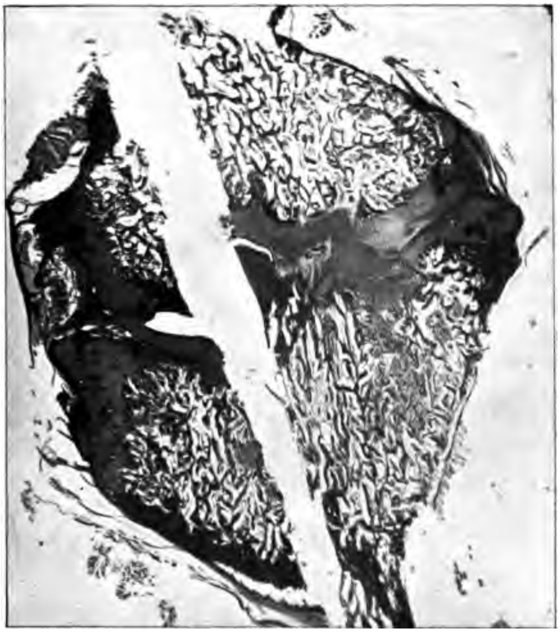


Fig. 88.—SECTIONS SHOWING THE RELATION OF CARTILAGINOUS AND BONY CALLUS. $\frac{1}{2}$-IN. OBJECTIVE.

A.—No. 48, the specimen shown in *Fig.* 52 *b*, after 34 days. The section is longitudinal, and passes tangential to the dense bone, through the external callus. The cartilage zone is opposite the line of fracture.

B.—No. 44, the specimen shown in *Fig.* 65 *b*, after 42 days. Two longitudinal sections through the external callus, showing the cartilage remaining at the line of fracture (right-hand section), and beneath the periosteum (left-hand section).

than elsewhere, and this is well shown in *Figs.* 47, 49, 53 *b*, 56 *b*, 60 *a*, and 65 *b*, and in microscopical sections in *Fig.* 88. It is usually absent, or present only in microscopical amount, when union is complete and when union has taken place in good position with fixation, and this is illustrated by *Figs.* 53 *a* and *c*, 69 *b*, 70 *b*, and 70 *c*. All my specimens seem to show that there is a direct conversion of osteoblasts into cartilage cells, and of cartilage cells into osteoblasts. The generally accepted statement that cartilage is not a constituent of human callus is probably incorrect, and due to the fact that the specimens on which the statement is founded were of an age when the cartilage has disappeared. Many observers who have studied early cases of human fracture have found that cartilage is abundantly present. Amongst these are Duhamel, Maas, Flourens, Hofmokel, Dupuytren, and Orth (quoted by Zondek). Ziegler gives details of a human complicated fracture above the ankle, eight weeks old, in which there was abundant cartilage, and he states that he has found it in over fifty human fractures ; and as recently as December 6, 1913, Morley, in the *British Medical Journal*, has described and figured luxuriant cartilage growth as resulting from a periosteal injury in a human femur.

On the Behaviour of Isolated Bone Fragments.—This subject, trending as it does on the large field of the transplantation of bone, is so difficult, and my experiments are so few, that I wish to speak with some reservation, realizing the dangers of drawing far-reaching conclusions from insufficient data.

There are three groups of experiments which bear upon this point.

The first deals with comminuted fracture, and is illustrated in *Fig.* 71 and the microphotos *Figs.* 89 *A* and *B*. In these, and particularly in *Figs.* 71 *b* and *c* and *Fig.* 89, it is seen that every isolated piece of bone acts as a centre of active bone proliferation, and forms a firm mass of ossified callus. Seeing what rapid callus formation occurred around these fragments in comminuted fractures, I thought it would be easy to demonstrate that bone-grafting would take place much more readily from bone chips than from large fragments of transplanted bone. But, unless the remaining groups of experiments are for some reason fallacious and exceptional, this is proved to be incorrect.

The second set of experiments dealing with isolated bone chips is illustrated in *Figs.* 83 *b* and *c*, 84 *b* and *c*, representing

3. That in all complete fractures there exists a very strong muscular force which tends to displace the fragments until the muscles are thrown out of action and a position of stability free from tension is acquired. This involves great deformity, consisting of shortening, overlapping, and angulation.

4. The operative treatment of fractures should aim at completely counteracting this displacing force. It should not only accurately replace the fragments, but do so in such a mechanically efficient way that displacement cannot occur.

5. The mere presence of an aseptic indifferent foreign body in the tissues has no ill effect upon their healing, unless there is an interposition of its substance between structures which ought to unite.

6. That the frictional grip between a bone and a screw will rapidly give way if subjected to much tension, owing to the absorption of the bone.

7. That the union of bones by plates and short screws is mechanically inefficient, because the screws are quickly pulled out of the bones.

8. Sepsis is often the result, and not the cause, of inefficient mechanical fixation.

9. Mechanical efficiency in the direct operative treatment of fractures can be attained in two ways : (*a*) By the use of long plates, and pins or bolts which transfix and hold the bone by some broad flange or nut ; and (*b*) By the use of strong, solid intramedullary pegs.

10. Perfect anatomical union and normal function usually result from either of the above methods. Normal, sound, and rapid repair is perfectly consistent with absolute rigidity.

11. Delay in union is a possible, though exceptional, result of perfect operative fixation of a fracture. It is due probably to interference with the blood-supply of the bone ends, and will cause no disadvantage if the mechanical fixation be so efficient as to hold the bones in good position for an indefinite time.

12. The fixation of transverse or slightly oblique fractures by encircling wire is unsatisfactory, because it is mechanically inefficient, and allows from the outset a mobility which delays union by interfering with the zone of repair.

13. All forms of absorbable pegs that I have tried are unsatisfactory, because they either break or bend before good union has occurred.

14. Metallic magnesium, when used as a peg, acts as a powerful stimulus to callus formation.

15. The natural position assumed by bones which are not fixed results in deformity, callus excess, or the formation of a false joint.

16. In the treatment of severely comminuted fractures, and in certain cases of open fracture, the best method of treatment is by a fixation of the main fragments, leaving the small pieces in position when strength of union is the chief object, and removing some of them when callus excess is likely to interfere with the mobility of a joint.

17. In the repair of bone defects: (*a*) Natural repair occurs rapidly when only part of the thickness of the bone is destroyed; (*b*) Fragments of bone used as a graft (from the same animal) form new bone very slowly if they are only loosely inserted in the gap; (*c*) Large pieces of bone used as grafts unite quickly, and form the centre of new bone growth, if they are tightly fixed to the raw surfaces of vascular bone.

18. The periosteum is the product, and not the mother, of bone. All the osteogenetic properties of the periosteum, whether in the repair of fractures or in grafting, are due to the more or less accidental presence of the outer layer of bone-cells adherent to its deep surface.

19. Living bone is the chief source and origin of callus, which grows mainly from its outer or periosteal surface, and to a less extent from its deep or medullary surface and its cut ends.

20. Cartilage is a constant stage in the transformation of bone granulation-tissue into bone. It is present chiefly (*a*) in early stages of repair, and (*b*) when there is much displacement and mobility; and it remains longest under the periosteum and at the line of fracture.

Table I.—RESULTS OF NINE EXPERIMENTS WITH SHORT PLATES AND SCREWS.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
23	17/5/11	R. T.	21	Large mass of callus. Lower screws out. Upper screws firm	Great angulation	Plate protruded from wound
24	17/5/11	R. T.	33	All screws out; screw holes enlarged and rounded. Some necrosis of both ends. False joint	Angulation and overlapping	
25	17/5/11	R. F.	42	Firm callus union. Upper screws out	Angular displacement and overlapping	
26	17/5/11	R. F.	21	Callus union. Screws out from lower end	Angular displacement and overlapping	
27	19/5/11	R. F.	38	All screws out. False joint	Angulation and overriding	
28	19/5 11	R. F.	31	Firm callus union. Upper screws out. Firm callus union	Overlapping and angular displacement	
31	19/5/11	C. T.	7	None, fibula fractured. Screws out from upper fragment	Good position	Sepsis
32	7/6/11	C. T.	19	Upper screws out. Early callus union. Necrosis of upper end	Angular overlapping and displacement	Sepsis
36	9/6/11	R. F.	37	Wires broken; plates loose. Large abscess cavity. Periostitis	Great deformity	Wound healed soundly; two plates and perforating wires

Summary.—Under conditions employed the method was quite useless. In every case the screws came out from one or both fragments. In four out of nine, sepsis complicated matters; in three of these the plates lay just beneath the skin. Plates used were $\frac{3}{4}$ in. long. Screws were $\frac{3}{16}$ in. and $\frac{1}{32}$ in., with metal thread.

Table II.—RESULTS OF OPERATIONS WITH LONG PLATES AND SPLIT PINS.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
48	22/2/12	C. T.	34	Firm. Callus in some excess growing over the plate. Cartilage at the site of fracture	Good	Good function. Plate was 2 in. long and $\frac{1}{16}$ in. thick
52	2/5/12	C. T.	42	No union. Very little callus	Good	Good function. Plate $1\frac{1}{2}$ in. long, $\frac{1}{16}$ in. thick
53	2/5/12	C. T.	42	Firm bony union. Minimum of callus	Good	Good function. Plate as in last
54	16/5/12	C. T.	28	Firm bone union. Small amount of callus	Good	Good function. Plate as in last
92	11/9/13	C. F.	53	Firm bone union	Good	Good function. Double plates

SUMMARY.—In all cases the four holes for the pins were bored in the bone before it was divided. This accounts for the uniformly good result anatomically. The pins were ordinary split or cotter pins, $\frac{1}{16}$ in. in diameter, passed through the whole thickness of the bone, and the ends turned back and cut short. The plate, which was nickel-plated steel, formed one quarter of a circle $\frac{5}{16}$ in. in diameter. In every case functional and anatomical perfection was gained. In an actual fracture there would be the important factors of accurate adjustment and the ultimate fate of the plate to be considered. Note the remarkable contrast between 52 and 53 as regards union. In the last case, 92, double flat plates were used.

Table III.—RESULTS OF EXPERIMENTS WITH ENCIRCLING METAL COLLARS.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
4	6/4/11	C. T.	1	None	Lower end had escaped from collar. Fibula fractured	Died, cause undetermined
9	26/4/11	C. T.	52	External periosteal callus outside plate deficient at one area. Ossified only at the edges. Union of bones by cartilage. Remarkable internal reconstruction	Good	Excellent function. Steel plate and wire
10	26/4/11	C. T.	10	None, but bone ends rough. Early callus	Good	Aluminium plate. Wound broke open, exposing plate
11	28/4/11	C. T.	13	Plate largely eroded. Early periosteal callus, lower fragment. No union	Good	Magnesium and wire. Good function. Skin became sore
14	1/5/11	C. T.	25	No bony union. Ends partly necrosed. Early callus growing over ends of collar	Good	Aluminium and wire. Excellent function. Fibula thickened opposite fracture
42	19/6/11	C. T.	28	Firm callus union. Tibia fractured	Overlapping and angulation	Wire only. Upper end escaped

SUMMARY.—Mechanically, the method is good. If properly carried out, the bones are kept in good position, and good function results; but the natural union is delayed greatly, the bone ends may undergo necrosis, and there is a marked tendency to opening of the wound, with exposure of the plate. Very instructive as to the origin of callus.

Table IV.—RESULTS OF SEVEN EXPERIMENTS WITH INTRAMEDULLARY PEGS—BONE.

NO.	DATE	ANIMAL AND BONE	PERIOD DAYS	REPAIR	ANATOMICAL RESULT	REMARKS
3	6/4/11	C. T.	5	None	Peg broken. Good alinement	Died, cause unknown
5	12/4/11	C. T.	17	Early callus filling angles	Peg broken. Slight lateral displacement	Slight skin suppuration
6	12/4/11	C. T.	44	Firm callus union. Callus partly cartilage, partly bone	Peg broken. Marked lateral displacement. Fibula fractured	Good active movements
7	21/4/11	C. T.	15	Early callus union	Peg broken. Displacement and overlapping	Some suppuration
15	5/5/11	R. F.	32	Extensive cartilaginous callus with false joint	Peg broken. Marked overlapping	
19	12/5/11	R. F.	45	Inflammatory process has overshadowed any healing	Peg broken out from one end of shaft. Extreme displacement	Osteo-periostitis. No apparent ill health or pain
20	12/5/11	R. F.	47	False joint, with a well-marked fibrous capsule	Peg broken. Marked displacement	

SUMMARY.—Mechanicallly, the method was a failure, because the bone pegs always broke. In three cases there was some suppuration, and in one this was of a serious character. Great displacement, excessive callus, and a tendency to the formation of a false joint were exhibited in the union when the fixation had given way.

Table V.—RESULTS OF FIVE EXPERIMENTS WITH INTRAMEDULLARY PEGS—DECALCIFIED BONE.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
8	21/4/11	C. T.	28	Callus well marked. Upper end of lower fragment is necrosed	Great overlapping. Fibula fractured	Marked displacement within few days
12	28/4/11	C. T.	29	Union by excessive callus. Necrosis of upper end of lower fragment	Great overlapping. Fibula fractured	Cat well and lively
17	9/5/11	R. T.	10	No union, but no necrosis	Overlapping and angular displacement	Leg put up in plaster
21	12/5/11	R. T.	38	Firm union by external callus	Overlapping with angular displacement	
39	19/6/11	C. T.	28	No union, but position maintained by wire. Necrosis of both ends	Good position	Good function

SUMMARY.—In the absence of other means of support, the method is useless, because the decalcified peg at once snaps.

Table VI.—RESULTS OF FIVE EXPERIMENTS WITH INTRAMEDULLARY PEGS—GELATIN (4), HORN (1).

GELATIN.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
33	7/6/11	C. T.	40	Union by abundant callus, not by bone. Fibula fractured	Good. The wire had kept the ends in apposition. Catgut unaltered	Wire used round oblique division
34	9/6/11	C. T.	22	Almost no repair; even callus absent. Necrosis of ends held by wire	Good, kept by wire	Wire round oblique section
40	19/6/11	C. T.	28	No repair. Ends held by wire necrosed	Good, held by wire	Wire round oblique section
41	19/6/11	C. T.	28	Slight callus repair. Necrosis of ends	Good	Wire round bone section
				HORN.		
45	8/2/12	C. T.	28	Slight callus. No bone union. Fibula fractured	Overlapping. Peg broken	Displacement evident in second week

SUMMARY.—As far as these few cases go, it is evident that absorbable pegs cannot alone hold the bone until union occurs. The effect of the wire, in holding the bones together but in causing necrosis of the bone ends, is important as showing the effect of interference with the periosteal blood-supply.

Table VII.—RESULTS OF SIX EXPERIMENTS WITH INTRAMEDULLARY PEGS—MAGNESIUM.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
29	19/5/11	R. F.	31	Excessive callus, in which is one small cavity with clear fluid. No bony union	Extreme overlapping, rotation, and angulation. Peg in advanced disintegration	Peg fitted loosely and soon broke. Wound healed well
30	19/5/11	R. F.	42	Exuberant callus and marked periostitis, especially of upper fragment. Several cavities filled with putty-like matter	Great displacement and deformity	Wound healed well. Peg broke
35	9/6/11	C. T.	60	Excessive callus union. Superficial part shows small septic cavity with slight necrosis	Good position. Slight angulation. Fibula and tibia embedded in large callus mass. Peg disintegrated	Wound sore. Good function
37	14/6/11	C. T.	55	Spindle-shaped callus mass. Firm union by this. Slight local aseptic necrosis	Excellent	Good function and healing
38	14/6/11	C. F.	55	Excess of callus. Periostitis	Great deformity	Bad function. Peg broke
22	12/5/11	R. F.	38	Upper fragment has split. Periostitis with large abscess	Great deformity	Magnalium rod. Fair function

SUMMARY.—The metal is too soft and easily broken to be relied on unless supported by another appliance. The great stimulation of callus formation is the outstanding feature.

Table VIII.—RESULTS OF SEVEN EXPERIMENTS WITH INTRAMEDULLARY PEGS—STEEL.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
43	25/1/12	C. F.	42	Callus rather excessive. Bone union	Perfect	Peg with fixed cross-piece. Perfect function
44	25/1/12	C. F.	42	Excess of callus, centre of which is cartilage. Bone not united	Perfect. Peg had slipped too far into lower fragment	Peg with wire. Perfect function
47	22/2/12	R. F.	34	Callus excess. Peg lies in centre of a cavity	Deformity: angulation and rotation	Bone splintered and surrounded by wire
49	7/3/12	R. F.	43	Callus excess. Firm union	Good. Peg had slipped too far into lower fragment	Good function
50	2/5/12	C. T.	42	No callus. No union	Good. Peg very firm	Excellent function
51	2/5/12	C. T.	14	Very slight callus. No bone union	Good	Animal never fed properly. Died
56	16/5/12	C. T.	34	Moderate callus. Early bone union	Good	Died of diarrhœa

Summary.—Of the above, No. 47 must be regarded separately, as an accident converted it into a comminuted fracture. All the rest did well. None showed sepsis. The repair is remarkably different. In three femurs the callus is in some excess. In the three tibias it is less than normal, and repair seems to be delayed. Functional and anatomical excellence in every case.

Table IX.—RESULTS OF SIX EXPERIMENTS WITH INTRAMEDULLARY PEGS—WIRE SPIRALS.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
61	13/6/12	C. F.	15	Callus in concavity	Extreme angulation	Deformity within first week. Spiral bent
62	27/6/12	C. T.	43	Bone thickened by periostitis. Callus union	Angulation. Fibula fractured	Slight sepsis in wound
63	27/6/12	C. T.	43	Callus union	Angulation. Fibula fractured in two places	
64		C. T.	43	Periostitis. Firm callus union	Angulation. Fibula fractured	Slight wound sepsis
66		C. T.	14	Necrosis of one end. No union	Some angulation	Wound sepsis
77		C. T.	28	Periosteal callus. No union	Slight angulation	

Summary.—In no case was the result satisfactory. It is not possible to construct wire spiral pegs of this size with sufficient rigidity.

Table X.—RESULTS OF SIX EXPERIMENTS WITH TRANSFIXION APPARATUS.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
55	16/5/12	C. T.	21	Early callus	Angulation. Fibula fractured	Faulty technique. Boring difficult. Soft parts torn. Wound suppurated
57	30/5/12	C. T.	14	Firm callus union	Excellent	Good technique. Good function
58	30/5/12	C. T.	18	No repair, callus or bony	Excellent	Good function. Never well. Died of distemper
59	30/5/12	C. T.	71	Bony union. Minimum callus	Excellent	Good function from 2nd week
60	13/6/12	C. T.	57	Bony union. Minimum callus	Excellent	Good function
65	27/6/12	C. T.	7	Early stages of repair	Excellent	Would not feed. Died of distemper

Summary.—Every case did well except the first, in which the technique was at fault. The good anatomical result, the repair with so little callus, and the early functional recovery, are very notable.

Table XI.—THREE EXPERIMENTS ON COMMINUTED FRACTURES WITH TRANSFIXION APPARATUS; FRAGMENTS AND PERIOSTEUM LEFT IN SITU.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
67	5/9/12	C. T.	28	Firm welding of fragments in callus	Good, with some thickening	Cat ran freely one week after operation
68	5/9/12	C. T.	42	Firm welding of fragments in callus	Angulation. Fibula fractured. Upper pin-hole too large	Good function
72	19/9/12	C. T.	28	Firm callus-mass embedding all the fragments	Good	Walks well

Summary. The result was good. Repair firm, with a tendency to callus excess and bony thickening. Repair is quicker and better than in those cases where either periosteum or fragments are removed.

Table XII.—FOUR EXPERIMENTS ON COMMINUTED FRACTURES WITH TRANSFIXION APPARATUS; REMOVAL OF LOOSE FRAGMENTS.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
69	12/9/12	C. T.	21	Definite solid mass of soft callus between the two ends	Angulation. Fracture of fibula	Limped badly. Upper pin only caught edge of tibia and had broken out
70	12/9/12	C. T.	42	Union by solid mass of calcareous callus, not rigid	Good	Walked with a limp
71	12/9/12	C. T.	21	Union by solid callus and by a splinter of bone	Good	Apparatus became unscrewed
73	19/9/12	C. T.	28	Restoration of bone by callus which is partly cartilage	Good	Walked badly

Summary.—Cartilaginous and fibrous callus is rapidly formed and replaces the lost bone, but ossification is long delayed.

Table XIII.—FOUR EXPERIMENTS ON COMMINUTED FRACTURES WITH TRANSFIXION APPARATUS; EXCLUSION OF PERIOSTEUM.

No.	Date	Animal and Bone	Period Days	Repair	Anatomical Result	Remarks
74	19/9/12	C. T.	1	None	Good	Died, cause not found
75	3/10/12	C. T.	42	Fragments appear to have grown together, but there is little union with bone beyond fracture. No external callus	Good. Slight angulation	Walked well. Aluminium plate
76	3/10/12	C. T.	21	No union. All fragments necrosed	Good	Sepsis
78		C. T.	35	Union of fragments to upper pair of main shaft. Periosteal callus growing over plate from the edges	Good	Walked badly

Summary.—It it clear that vitality and repair are preserved, but that callus formation, and therefore effective rapid union, is greatly delayed when the periosteum is separated from the seat of fracture.

Table XIV.—SHOWING THE RESULTS OF UNILATERAL FIXATION OF THE FEMUR.

No.	Date	Period Days	Repair	Anatomical Result	Remarks
81	5/6/13	14	Good internal callus	Gross deformity	Upper screw came out
82	5/6/13	42	Union chiefly by internal callus	Some angulation	Apparent success
87	26/6/13	21	Internal callus only	Gross deformity	Upper screw came out
90	28/8/13	14	None	Gross deformity	Upper screw came out

Summary.—These failures show that a single bone cannot be kept in good position by an apparatus which holds it by two points only without exercising continuous extension.

Table XV.—SHOWING RESULTS OF THE SUBPERIOSTEAL REMOVAL OF A PIECE OF THE WHOLE THICKNESS OF THE BONE.

No.	Date	Period Days	Repair	Anatomical Result	Remarks
79	15/5/13	35	Internal callus in upper fragment. Nothing in gap. Callus excess round fibula	Fibula had broken	Good function
80	15/5/13	14	Internal callus in upper fragment	Good position	Died—cause unknown
83	19/6/13	7	No repair	Good position	Good function. Died—cause unknown
84	19/6/13	7	Early stage of internal callus under rubber	Good position	Rubber tied over bone ends
85	19/6/13	42	Internal callus in both ends under the rubber, and a mass of cartilaginous and bony callus formed from periosteum in gap	Good position	Rubber tied over bone ends. Good function

SUMMARY.—From a practical point of view, this small series of cases shows that in the majority of cases bone is formed very scantily or not at all from bone ends which are separated from one another by a considerable gap.

Table XVI.—SHOWING RESULTS OF EXPERIMENTS ON REMOVAL OF A PART OF THE THICKNESS OF A BONE.

No.	Date	Period Days	Remarks
96	12/9/13	28	Gap is partly filled with cartilaginous callus. There is new bone formed in the marrow cavity
95	12/9/13	60	Gap is almost completely filled with bone of normal density
94	12/9/13	60	Gap completely filled with bone of normal density
91	28/8/13	63	Gap is filled with bone, and the marrow cavity somewhat encroached upon by new dense bone

SUMMARY.—A large defect in the bone, affecting only half its thickness, is rapidly made good, probably by regeneration from the raw bone surface left.

Table XVII.—SHOWING RESULTS AFTER GRAFTING BONE IN A DEFECT.

No.	Date	Period Days	Remarks
86	26/6/13	49	A single piece of bone used to fill the defect. Solid union
88	15/7/13	15	Gap filled with bone chips. Chips lay embedded in cellular callus
89	15/7/13	70	Gap filled with bone chips. Chips lie in cartilaginous callus, but there is no solid union

SUMMARY.—From these few experiments it appears that a large piece of bone firmly fixed to living bone acts better as a bone graft than small chips lying loosely.

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Chapter VI

THE OPERATIVE TREATMENT OF FRACTURES

GENERAL CONSIDERATION OF INDICATIONS AND TECHNIQUE.

MOST surgeons are agreed that fractures without displacement are to be treated by massage and movement and intermittent apparatus; that cases with displacement must have immediate extension applied; and if this fails to give good reduction, operation is to be undertaken. But the matter cannot be concluded as simply as this. For, on the one hand, there are some cases in which, in spite of considerable persistence of displacement, a good result may be looked for eventually : whereas in other cases, though the displacement can be reduced by the apparatus and extension, there is a probability that it may quickly recur, or that it will yield under the body weight, or that firm union will require a very long period under a non-operative régime.

In general terms, it may be said that the following groups represent the factors which will determine in most cases whether an operative or non-operative method should be employed :—

Factors Favouring Success of Non-operative Methods.

The youth of the patient—i.e., the period of active bone growth. Until puberty there is great capacity for bone repair and restoration of form and function.
Subperiosteal or partial fracture.
Fractures with little or no displacement.
Fractures of only one of the paired bones of the forearm or lower leg, especially of the ulna or fibula.
The majority of arm fractures.

Factors which Indicate Advisability of Operation.

Adult age. In fully grown bones, especially those of old people, there is good capacity for repair, but little for restitution of mal-union.
Fractures with gross displacement, especially oblique and spiral fractures.
Fractures of the shaft of the femur, and of both tibia and fibula.
Fractures into or near the elbow, knee, and ankle.

There will always be certain groups of cases about which surgeons will fail to agree. A surgeon will advise non-operative or operative treatment in such cases according as he has skill, confidence, and experience in a particular method. And further, there will always be some cases about which a broad-minded surgeon will be in doubt, and such cases can only be decided on their own merits, and not according to any general law.

There is a week in which to make this decision, and it is well to avoid the two extremes of deciding on operation too quickly or postponing it too long. If anatomical restitution of form is to be the chief guide, it is unreasonable to act upon a skiagram taken before extension was applied; and it is foolish to wait until a mal-union has occurred between the bones. It is quite certain that no fair judgement can be made in this matter by anyone who has not mastered both the non-operative and the operative treatment of fractures. The enthusiast for bloodless surgery will be liable to wait far too long trying his manipulations in some hopeless case of displacement; whilst the enthusiast for operation will give no time for a reasonable attempt at non-operative reduction in many a case which would have yielded quite simply to this treatment. I wish to make it quite clear that I am not advocating the treatment of all cases by non-operative means, reserving the operation for those in which the former has failed; but simply that in doubtful cases one week's trial of really efficient extension should be given, and its results judged by the *x* rays before operation be decided upon.

COMPARISON OF NON-OPERATIVE AND OPERATIVE TREATMENT OF FRACTURES.

In the broad sense of the word, it would seem to be absurd and useless to institute a 'comparison' between the results of non-operative and operative treatment of fractures. And yet one often hears the question asked, "Do you believe in operating on fractures?" As well might one ask "Do you believe in drugs?"—or institute a comparison between the non-operative and the operative treatment of dyspepsia. Personally, I have very little doubt that if the system of treating every case of dyspepsia by operation were to be compared with that of treating all such cases without operation, the results of the former would be very much better than the latter. Both plans would be criminal.

Similarly, to inquire whether the non-operative or operative methods of treating fractures give the better result is to assume that there is a responsible surgeon who would suggest that no fracture should be submitted to operation on the one hand, or on the other hand that every fracture should be dealt with by the knife. The most conservative surgeon would not allow a fractured patella with much displacement to go unsutured, nor would the most ardent advocate of operations suggest an open attack upon a subperiosteal fracture of the fibula without displacement. Therefore, the main problem must ever be, not non-operative versus operative methods, but rather the selection of those cases suitable for the one method or the other.

However, the comparison between the two groups of methods has recently been seriously undertaken by a committee of the Surgical Section of the British Medical Association, and they have, in spite of the illogical and impossible nature of their task, produced a most valuable contribution to the literature of fractures. They have examined over 2900 cases, and not only recorded the remote results of all of these, but they have so carefully arranged and analyzed their figures, that their results form a mine of information, and an authoritative standard by which all subsequent fracture work can be measured and with which it can be compared. They admit, that " it is undesirable to attempt to draw any final conclusions from this material as to the relative value of operative or non-operative treatment." Taking all cases together, the non-operative methods show 70·4 per cent good functional results, whilst operative claim 79·1 per cent. On the other hand, the non-operative produces 11·8 per cent really bad results, and the operative 9·5 per cent. So that on this basis, which shows the operative method in its least favourable light, there is this to be claimed, that operative methods get 9 per cent more good results and 2 per cent fewer bad results than the non-operative. If the cases are divided into age groups, and only those considered above 15 years, then the results of operative are 21 per cent better than those of non-operative methods.

Such figures will be regarded very differently by different observers. If there are any who think that all fractures could be treated by the one class of method or the other, then to such it will appear very doubtful whether only 9 per cent better results for operative methods is justification for submitting 81 per cent of patients to operation, who would have done just as well without it. But to the surgeon who thinks that operations should be reserved for the more complicated types of fractures, such figures will prove at once encouraging and stimulating, for they show that operations can produce better results in complicated cases than the conservative methods do in the simplest.

The fact that out of a total of 2904 cases 2596 were non-operative and 308 operative is pretty clear evidence that at the period of observation, as only one out of every ten cases was operated upon, these presumably were the most difficult and unpromising types. But without some knowledge as to how cases were selected for operation, the figures can afford us no basis of comparison.

The great and lasting value of the Fracture Committee's Report consists in the careful analysis of the anatomical and functional results of the large number of the non-operative cases they examined. Of the most fundamental importance is their demonstration of the dependence of good function upon perfect anatomical restoration. Good form secures good function in 90 per cent of cases, whereas moderate or bad restoration of form leads to bad function in 70 per cent.

It is particularly interesting to notice in which groups of cases the non-operative methods have given a high proportion of bad results, because this must give us a very significant indication as to the direction in which our operative activities may usefully be turned in the future. I have selected those cases only of patients over 15 years, because, in general terms, there is but little scope for operative treatment in the majority of the closed fractures of children.

Region of Fracture	Number of Cases above 15 Years	Cases with Good Functional Result	
		Number	Percentage
Neck of femur	87	24	27
Upper third of femur	49	23	47
Lower end of femur	10	4	40
Tibia and fibula (simultaneous) ..	432	275	64
Pott's fracture	238	111	47
Supracondylic fracture of humerus ..	11	4	36

If we ask to what extent operators have attempted to deal with these groups of fractures, we find clear evidence that with these very cases, in which there is so much need for improved methods, surgeons have done but little. Of primary operations on adults there have only been the following :—

Neck of femur	0
Upper third of femur	0
Lower end of femur	1
Tibia and fibula	20
Pott's fracture	4
Humerus, supracondylic	0

And of these, the only group containing enough cases to consider the proportion of successes—viz., that of the simultaneous fracture of the shafts of the tibia and fibula—the good functional results have only been 13 out of 20, or 65 per cent.

The following inferences from these figures seem to be justified :—

1. In these groups of cases an improved method of treating adult fractures is greatly needed.
2. There is not any generally accepted method of operative treatment to meet this difficulty in any of these groups, with the exception of fractures of the shafts of the tibia and fibula.
3. At the date of the Report, it was in that group of cases which gives the best results to non-operative methods (tibia and fibula) that there has been the greatest activity in operating, whereas in those groups where there has been the greatest failure of the old methods, the new surgery has done almost nothing.
4. Even in the one class where most operating has been done (tibias and fibulas) the results are only 1 per cent better than those obtained by conservatism.

The Period at which to Operate.—All operations for fracture ought to be performed within ten days of the accident. There are, however, several reasons which delay operation, some good, others bad. On the whole I think there is nothing in favour of immediate operation. Severe accidents cause much shock, and a few days are required to overcome this.

The complication of fat embolism, although a rare one, ought not to be entirely ignored, and if it occurs, its symptoms will be manifest within the first few days, and any operation done in such a case may be associated with a fatal result for which the operation will get the credit. In all closed fractures the exact anatomical condition cannot be ascertained without an *x*-ray picture, and this usually necessitates some delay. It is a wise rule never to decide upon operation or upon the exact type of operation which is to be carried out until several good skiagrams have been seen.

The existence of comminution, the presence of a tumour or cyst which caused the fracture, and the shape of the broken ends, are instances of the facts which must be known accurately by means of the *x* rays before operating.

In open fractures this does not apply to the same extent, but in such cases there are other reasons, to be discussed later, which make it much wiser to delay directly dealing with the bone until the wound has healed. And lastly, as has been repeatedly urged in the preceding chapters, it is in many cases quite impossible to determine whether an operation is necessary at all, until certain methods of non-operative treatment have been given a fair trial. This can be fairly tested within a week or ten days, at the end of which period the operation can be done just as easily as directly after the accident.

There are certain cases in which it is not worth while, apart from exceptional circumstances, to attempt non-operative treatment; but the determination of these will always be a matter for some difference of opinion. I would state them to be as follows: Fracture of the olecranon and the patella with distinct separation of the fragments; The majority of fractures of the femur and of both leg bones with gross displacement in adults who are active and healthy; Fractures into the large joints, or fracture-dislocations where the dislocation cannot be reduced. In these cases operations if properly done will give so much quicker, and probably better, results than non-operative methods, that I should always operate directly I were in possession of the necessary *x*-ray data.

But there are other circumstances which only too often cause a long postponement of the operation. The presence of a septic wound or injured skin, delayed union of the bones, and faulty union of a fracture treated by non-operative methods: these all involve a delay of weeks or months before the open treatment. Usually the surgeon who has to undertake it has no responsibility for the delay which has occurred. But it cannot be too strongly urged that the treatment by operation at these late stages is far more difficult and less satisfactory than when it is done early. Not only is there faulty union to be severed, and a permanent contraction of the soft parts to be overcome, but the actual form of the bones and joints has become modified so that a restitution *ad integrum* is no longer possible.

Preliminary Extension Treatment.—One of the greatest of the technical difficulties of any operation is the reduction of much overlapping of the fragments in a muscular limb, especially when the fracture has taken place some time previously and has only been tied up on a splint.

It will greatly facilitate the operation if full weight extension by plaster strapping, or by transfixion, be applied for a few days before operating. When there is displacement of several weeks' duration it is well worth while to use the transfixion method. It is not only that by this preliminary the operation is made much easier, but also that the gradual stretching of the soft parts does much less damage, and the final fixation of the bones will be carried out under more favourable conditions.

The Problem of Asepsis.—Previous writers on the subject of operative treatment of fractures have quite rightly laid great stress upon the necessity of the attainment of asepsis. But I have been convinced by my experimental work, as well as by clinical observation, that the relation of sepsis to fracture operations has been somewhat misunderstood. I have demonstrated that the sepsis which often follows these operations is probably post-operative in its origin: that it is the result of insecure and wobbly fixation and the use of foreign bodies which become loose in the tissues. If the operation is done with the least possible dragging and tearing; if all hæmorrhage is arrested; and above all, if the bones are securely fixed together by a mechanically efficient method, then straightforward healing will take place with as much certainty in the case of bones as in that of the soft tissues. Asepsis should be absolute, and for this the most important and most difficult condition is the prevention of the skin surfaces from contaminating the wound. But there is neither reason nor logic in the ritual which decrees that the gloved finger shall never touch the wound or anything which enters the wound. Such a ritual was invented in the days before the era of gloves, when surgeons were accustomed to contaminate their naked hands with septic operations; and under such conditions it may well have been regarded as essential. But now that gloves are worn it is no longer necessary, and with a very little experience and the use of proper instruments the risk of tearing a glove is reduced to a minimum. Even this risk may be overcome by wearing cotton gloves over the rubber ones, and such a precaution imposes a far less handicap upon the operator than the use of long-handled instruments and the loss of the use of the finger-tips at various stages of the process.

That the fingers should not be used as retractors or in dragging fragments of bone into position is quite clear, because such methods imply clumsy manipulation and involve the danger of tearing the gloves. But the adjustment of screws and nuts, the estimation of the correct position of the bone fragments, and the guiding of the points of hooks or retractors, can be done by the fingers in a way which no instrument is capable of doing. The difficulties of these bone operations are great enough with all possible assistance, and there is no need to add to these difficulties by imposing upon the operator a quite needless restriction.

It is of the utmost importance in the securing of asepsis to exclude with great care and exactitude the skin from contact with the wound or with the operator's finger. Clipping towels or gauze to the edges of the incision is the usual method employed for this purpose; but it is unsatisfactory, because the clips, if sufficiently numerous to serve their purpose, are in the way of the operation, and there is apt to be a piece of skin left exposed at each end of the cut. It is difficult to attach a towel to the edges of anything but a straight cut, and if there are two incisions, as in the operation for fracture of both arm-bones, it is impossible to protect both wounds adequately by separate pieces of towel or gauze.

There is a very simple way of overcoming these difficulties, which is by the use of the tubular woven material known as stockingette. The limb is painted first with iodine (I always use a 10 per cent solution), and then with mastisol, and the previously sterilized piece of stockingette is slipped on over it and tied in position by ligatures or tapes. In the case of a thigh it is best to use one leg of a woven pair of drawers. The incision or incisions are then made through this material, and the edges of the fabric exactly correspond to those of the skin wounds, to which they are at once sewn by a continuous blanket stitch. This takes a little longer than the towel and clips, but it is time well spent, because however long and difficult the operation, the skin can never become exposed, and there are no instruments hanging on the edges of the wound to embarrass operative procedures.

On the Planning of the Incisions.—The principal thing to secure in the incision is a free access to the bone. It should therefore either be of such ample length as to give good exposure, or else it should be formed as a flap, which is most useful in certain cases. The making of a long clean cut (as from the great trochanter to the external condyle of the femur) will do much less damage than dragging and tearing the tissues through a short incision. The flap incision is of value in bones like the olecranon, patella, or great trochanter, where the fracture lies just beneath the skin. It not only gives good access to the part, but secures that the skin incision shall not lie just over the sutured bone. In the case of thin limbs, and especially the shin, it will be of advantage, when there is much shortening, to make a bayonet-shaped instead of a straight incision, for this will, when the limb is lengthened, come together in a straight line with but little tension, as the transverse cut then becomes longitudinal.

In certain situations—for example, the lower end of the humerus and the lower end of the femur—it is far better to make opposite incisions than to attempt to work only from one side.

The Retraction and Protection of the Soft Parts.—Having made the incision and fixed the edges of the stockingette to it by suture, the soft parts are divided until the bone is exposed. This must be carefully planned according to the anatomy of the part, so as to avoid cutting across important muscles, vessels, or nerves. Some of the details of this anatomy will be dealt with in a later chapter.

When the bone has been reached, and after any loose clot has been removed, the periosteum is cut through for the entire length of the wound on both fragments. It is very important that this should be done before the overlying soft parts have been separated from the bone, because it allows of the periosteum being separated from the bone together with the soft parts, and when the latter are brought together at the conclusion of the operation the periosteum comes with them and covers over the plates and wire which have been used for fixation. These will then become buried in the callus which fills up the space between bone and periosteum.

Having sufficiently divided all the overlying soft parts, including the periosteum, the next step is to secure their adequate retraction and protection. First, all bleeding points should be secured and tied with fine chromic catgut. A sterile towel with a slit about 8 inches long is placed over the bone so that the latter lies in the slit. A special retractor with blunt-pointed ends is then passed under each fragment, and pushed through until one half of the retractor lies on each side of the bone. These retractors are of two patterns. One consists of a simple strip of German silver 12 in. long by ½ in. wide. This is thrust underneath the bone as far as its centre, and then the two halves are bent back so as to hold back the muscles and skin behind the bone surface. This is quite sufficient in dealing with small limbs and superficial bones. But in a muscular part, where the bone lies deep, a specially shaped retractor is necessary (*Fig.* 90). This is formed in two halves. One is a straight shank ending in a semi-circular hook which is slipped under the bone, the other is a simple bar which screws into one of three holes in the hooked extremity of the first. By this means the soft parts can be held back to the level of the axis of the bone (A), or to a point a little less (B), or a little more than this (C). Both of these retractors have the advantage of being self-retaining. If the skin incision has been made of sufficient length, the soft parts are by these means retracted well away from the bone, and the towel covers their surface. This not only makes all subsequent manipulation much easier by giving a clear field, but it also serves to protect the muscles from injury by drills or other instruments in the course of the bone suture.

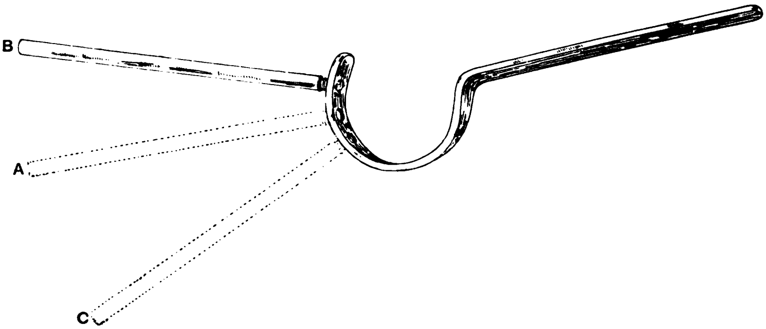

Fig. 90.—Author's retractor. The instrument is made in two halves. The sickle-shaped part is passed under the bone, and the other portion is screwed into place in one of three possible positions, thus giving different degrees of retraction.

The Reduction of Displacement.—Probably the greatest and most unpleasant surprise that awaits any reckless person who, without any special preparation or experience, operates upon a fracture for the first time, is the great difficulty in replacing the bone fragments in their proper positions. The bone is deeply buried in muscle, and it is hard to see exactly what is the relative position of the two ends, and still more is it difficult to grasp them in such a way as to exercise strong traction. An assistant or a nurse is requisitioned to pull on the limb, but at the most critical moment tension is relaxed and the bone again slips out of place. Or a lever is used, passed over one end and catching the other, to draw the overlapping fragment into alinement; if the break is transverse or jagged, this leverage will not, except by accident, correct the rotation; if the break is oblique, it will not hold the fragments in position for a moment after the lever is withdrawn. Working under such conditions is tiring to the muscles and trying to the temper, and produces much bruising of the parts round the bone. Apart from the use of variously shaped levers, which may help in reduction, but which cannot hold the parts in that position, there have been two other systems employed to reduce the displacement, both of which are much more precise. One is the attachment to the limb by plaster of a traction stirrup, and this is pulled upon during the operation by means either of a screw or a system of levers. This method is not good. If the displacement is recent and easily reduced, then this ought to be done prior to the operation as suggested above. On the other hand, if (as in an old fracture of the femur) powerful traction is necessary, this surely ought to be applied to the lower fragment directly. If the femur is pulled upon by traction on the foot, not only is much of the traction force lost, but in pulling upon the elastic ligaments of the ankle and knee these structures are liable to injury. If any system of external traction is to be used, it is far better to employ a transfixing-pin through the lower fragment, and this can then be pulled upon and also used as a means of rotating the bone.

In the double transfixion apparatus described in Chapter IV, we have a device which greatly simplifies the whole problem, and substitutes a very powerful mechanical extension, capable of the finest adjustment, for the haphazard methods of " pulling as hard as you can." It will give up to 100 lb. of extending force, and it will allow of, and indeed may be used to bring about, alteration in alinement, lateral deviation, and rotation of the fragments. Each movement of adjustment is carried out with power and precision, and not by uncertain pulls or jerks. When the correct position has been attained, the bone is rigidly held there by tightening the screw-nuts of the apparatus, and the operative fixation can be undertaken at leisure. The apparatus lies altogether outside the field of operation, and does not occupy any of the space inside the wound. I have only recently devised this instrument, and therefore I still describe the older forms of extension and fixation clamps which have been in use for some years.

The other system of reduction is by internal clamps and screws, of which there have been several different patterns. But some of these are not secured to the bone firmly enough, and when the traction is exerted they are apt to slip along the bone. Others form such a rigid apparatus that in obtaining extension in the axis of the bone the mobility to secure rotation or lateral movement is lost.

It is necessary that the bone fragments should be so firmly grasped that no slipping is possible, and yet there should be free mobility left to the bones so that they can be readily moved in three directions, i.e., along their axis, at right angles to their axis, or in a rotatory direction.

The apparatus that I have used is of three different patterns. That for small bones, such as the metacarpals or the radius or ulna, is shown in *Fig.* 91.

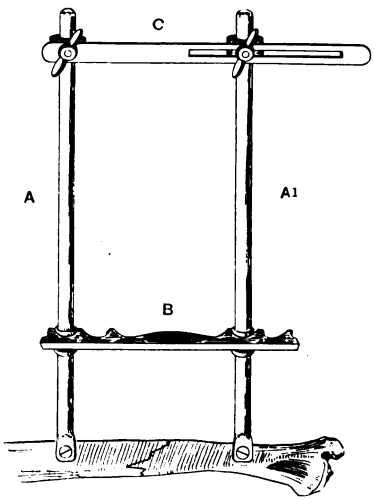

Fig. 91.—Fixation and extension clamp for small bones. In this pattern the fixed points of the clamp can be quite close together.

It consists of two steel bars (A, A1) each of which carries a screw at one end. This screw fits loosely in the bar, and is screwed into the bone. It is ½ in. long and ⅛ in. thick, with a self-tapping point. Holes are bored in the bone ends about 1½ in. from the fracture, and the bars A, A1 are screwed to the bones so as to allow free movement of the bars on the screws. The cross-piece B, which consists of a notched rod, is then adjusted to act as a fulcrum to the bars A, A1. By pressing together the handles of A, A1 the bones are separated from one another, whilst any lateral or rotatory deviation can be corrected at the same time. The apparatus is locked in position by the slotted rod **C**, screwed to the handles of **A**, **A1**.

The second pattern consists of two metal drills which are screwed into the fragments of bone, and then whilst held are separated from one another by a reversed screw tube and rods fitting over the grooves on the shanks of the drills (*Fig.* 92). The locking is similar to that in the last pattern.

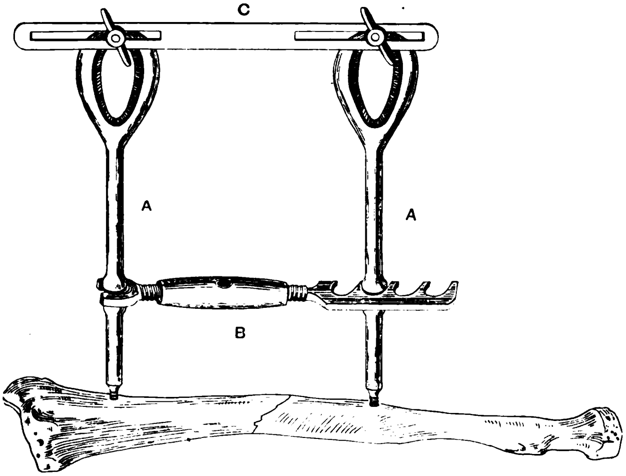

Fig. 92.—Fixation and extension clamp for small bones.

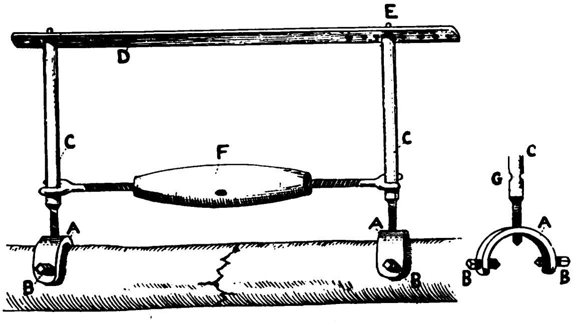

Fig. 93.—Fixation and extension clamp for large bones. The horseshoes A, A go over the shaft, which is grasped by the screws B, B. and also by the points of C, C. C, C are steel bars screwed into A, A, and separated from one another by the horn buckle F, which fits into the groove G on the shank of C. When adjusted in correct position, the ends of C, C are fixed in a perforated bar D. (From the *Lancet*, Feb. 21, 1914.)

The third apparatus (*Fig.* 93) is on exactly the same principle, but is adapted for larger bones, such as the femur. In this, the arms of the clamps are fixed to the bone by means of cutting screws in a horseshoe-shaped piece of metal. The two screws (B, B) are adjusted first, and they bite into the bone in opposite directions. The third screw is at the end of the main clamp handle, and it is not tightened until the preliminary leverage action has been accomplished. After this the clamp handles are held parallel, and the final adjustment is made by lengthening the cross-bar by screw action. When the bones are in perfect position the clamps are fixed by the locking bar, and the apparatus remains in place whilst the plates or other fixation apparatus is being adjusted.

FIXATION OF THE FRAGMENTS.

We must now consider the act of fixing the bones, and a few words are necessary with regard to general principles. Abundant experimental evidence has been adduced in the preceding chapter for regarding the mechanical efficiency of fixation as of the very first and highest importance. Bones need to be so firmly united that they will neither work loose by muscular action, nor yield before the body weight. Whenever an open operation is considered necessary for a fracture, we should have at our command methods of fixation which fulfil these conditions, otherwise we subject the patient to all the disadvantages of the operation without a proportionate benefit.

To operate upon a fracture and then depend upon a splint with long immobilization to prevent displacement, is in my opinion a weak compromise. I would therefore preface the remarks on the fixation of bones by saying that whatever method is employed ought to be capable of holding bones firmly without splint or immobilization for an indefinite time.

INTRAMEDULLARY PEGS.

The use of intramedullary pegs which just fit into the hollow cavities of the long bones has much to recommend it. It is very simple; it allows of the use of materials like bone or ivory which ultimately become absorbed; it anatomically ensures the correct alinement of the bone; and, whilst it is absolutely secure from displacement, it allows slight movement between the bone ends, which promotes callus production.

It can often be applied through a comparatively small incision, but it involves an extensive boring of the medullary cavity in order to make the pegs fit snugly. The amount of movement allowed between the bone ends is often productive of great callus excess, and if any sepsis should arise, it is impossible to remove the peg without serious injury to the bone. And lastly, unless certain means are taken for carrying it out, the method is difficult of execution. It will be best first to describe the technique of the method before discussing its indications.

Short Peg with Fixed Cross-piece (*Fig.* 94).—This is the simplest type of peg, but it is only to be used when there is no tendency to angulation of the bone. I have used these pegs made both of metal and of ivory. The latter is perhaps the most ideal material, but it is important that the peg should be made of one solid piece, and not with a small cross-piece driven into a hole in the centre of the peg, for this weakens the peg at the very point where it ought to have its full strength.

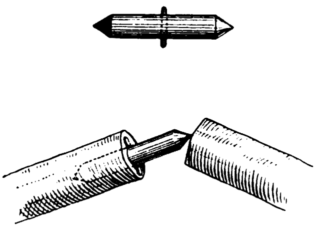

Fig. 94.—Intramedullary pegs with fixed cross-pieces. The lower figure shows the method of inserting in position.

The pegs of the most useful size are $1\frac{1}{2}$ in. long, and $\frac{1}{8}$ in., $\frac{5}{32}$ in., and $\frac{3}{16}$ in. thick. One is chosen which tightly fits both ends of the bone, which are bored out by a twist drill so that the peg can readily be inserted into either up to the centre cross-piece. A groove is cut by a triangular file across the end of one fragment to lodge the cross-piece, so that it shall not prevent the broken ends fitting closely together. The peg is now placed in the end so prepared, and then both fragments are seized in forceps and separated from one another for $\frac{3}{4}$ in., so that the empty fragment can be slipped over the projecting peg. A certain amount of angulation is usually necessary for this manœuvre. If two bones, e.g., the radius and ulna, are to be treated, then this final act of adjustment of the fragments over the pegs should be made simultaneously.

The Long Peg introduced by Wire Traction (*Fig.* 95).—These pegs are of the following sizes: $\frac{1}{8}$ in., $\frac{5}{32}$ in., $\frac{3}{16}$ in., $\frac{7}{32}$ in., and $\frac{1}{4}$ in. thick by 2 in. long; and $\frac{9}{32}$ in., $\frac{5}{16}$ in., $\frac{11}{32}$ in., $\frac{3}{8}$ in., $\frac{13}{32}$ in., $\frac{7}{16}$ in., $\frac{15}{32}$ in., $\frac{1}{2}$ in. thick by 3 in. long. Those below $\frac{1}{4}$ in. in thickness are made of nickel-plated steel, and those from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. of bone. Each peg has a small transverse perforation at its middle, and a groove along each side, to take the traction wire.

After the fracture has been exposed, each end is brought out into the wound in turn, and bored by a twist drill of such a size that the peg will easily run up into its cavity. One fragment must be bored far enough to take the whole peg, the other need only accommodate it for half its length. When this has been done, the deeply bored fragment has the sharp inner edge bevelled off by means of a conical reamer, in order to allow the traction-wire to slip over it easily. Then the peg is threaded with about 18 in. of No. 20 steel wire, and the two ends of the wire being held snugly in the grooves, the peg is inserted for its whole length into the fragment prepared for it. Then the bone clamps are fixed on to the fractured bone, and the two ends are separated from one another with a short interval between, and accurately alined. This is an important point, because if manual reposition is depended upon and the jagged ends are crowded together, the traction wire will become so nipped that effective traction cannot be undertaken ; but if the bones are held firmly apart and in an exact line with one another, by pulling on the ends of the wire the peg will slip into its place (*Figs.* 95, 96). It may be prevented from slipping up and down the bone by suitably tying the ends of the traction wire round some outstanding fragments of bone ; but I have known this device fail, and since this experience I have preferred (in the case of bone pegs) to drill a ⅛-in. hole through each fragment right into the peg, about an inch from the fracture, and then drive in an ivory nail. This not only prevents

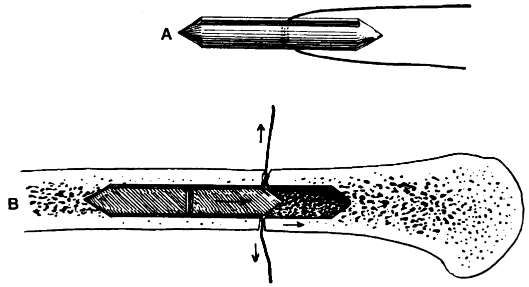

Fig. 95.—A, Long peg, grooved at the side to allow the wire to lie in its length. B, Peg in position ready for pulling into the right-hand fragment.

the peg from slipping, but it limits the amount of rotatory movement at the seat of fracture.

The Adjustable Peg (*Fig.* 97).—One other type of peg is to be mentioned. It will have been noticed in the above account that a large assortment of pegs and drills (13 of each) must be at hand; and further, that a good deal of drilling and fitting is necessary.

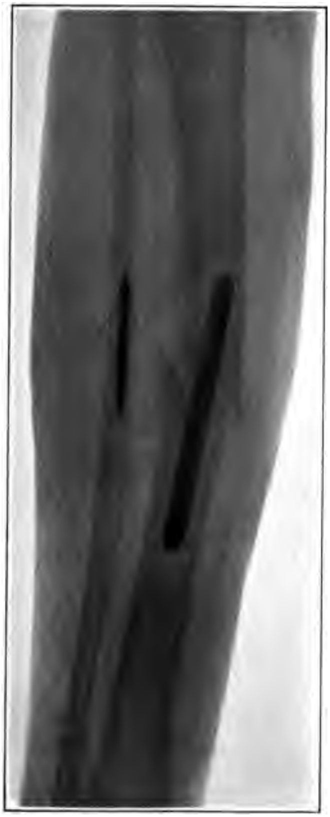

Fig. 96.—Fracture of both bones of the leg treated by pegging. The peg in the tibia is of bone; that in the fibula is of metal.

The adjustable peg will fit any bone with an internal diameter of 3/8 in. to 1/2 in.—practically any adult humerus, femur, or tibia. When it is closed it measures in cross-section 1/4 in. by 3/8 in., but when open it forms a part of a 1/2-in. cylinder. It consists of four pieces of ivory, hinged on one another after the manner of a parallel ruler. A screw in the middle of one long piece serves to adjust and fix the device. In order to use the peg, the screw is first removed, and the hole threaded with fine wire. The peg is now inserted into one fragment in the closed position. The bone ends being held in the clamps, the peg is drawn back into the second fragment by means of the wire, and the screw-hole brought into view between the broken ends. The wire is now removed, and the screw put into its place and tightened up so that the peg exactly fits the interior of the bone. The ultimate rigidity obtained by this device is much greater than can be secured by the most accurate boring for the solid pegs.

The Applicability of the Pegging Methods.—In its simplicity and mechanical efficiency the pegging of fractures is superior to plating; but it has certain drawbacks and limitations which greatly restrict its scope. When used for a femur, especially in a young adult, it does not as rigidly maintain alinement as does the bolted plate method. It allows so much play between the bone ends that there is apt to be a great callus excess. It is unsuitable if there is any comminution at the site of fracture.

I believe its usefulness to be restricted to transverse fractures of the femur, humerus, and of both forearm bones. In the two former I would use the adjustable peg, and in the latter the short pegs with the fixed crosspiece. In both these situations there is this great advantage, that the use of these pegs does not require a long incision nor an extensive stripping of the soft parts from the bones.

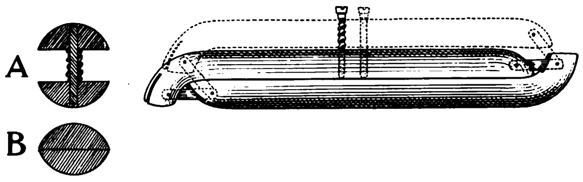

Fig. 97.—The adjustable peg. A. Cross-section, open. B. Cross-section, closed.

The Use of Wire.

Until quite recently, in all operations for uniting bones, silver wire was employed, and it is still a common thing to speak of 'wiring' fractures as though this represented the routine operation. But it was very soon evident, when operations were proposed for the attainment of perfect results, instead of being merely makeshift devices for dealing with bad open fractures, that 'wiring' as it was then done was very unsatisfactory. Now that the plating of fractures has been introduced and widely practised, 'wiring' has not only been generally abandoned, but has almost fallen into contempt.

It is quite worth while to consider the factors which are concerned in the use of wire, to determine whether it ought to retain any place in our methods of treatment. First, then, as to the material of which suture wire is composed. Silver has been used, not only because it is soft and easily manipulated, but probably with an old superstitious idea of the value of one of the precious metals. But it is, in reality, a somewhat untrustworthy material. It is a weak suture at its best, and its strength varies very much according to the way in which it is prepared, so that unless every sample is properly tested there is no reliability to be placed upon it. Again, it has been shown that silver quickly becomes converted into the sulphide when buried in the tissues, and this rapidly weakens the wire. Skiagraphy has shown that, not only in fractures, but even when silver wire is used as a filagree in the muscle planes of the abdominal wall, it generally becomes broken up within a short time if it is subject to any tension or movement.

Wire made of aluminium-bronze or of plated copper is in some ways a good material, but the copper is a powerful irritant poison in the tissues, which makes me disinclined to use it in either of these forms. In experiments where bronze wire has been used, there is always an area of green discolouration in the tissues all around it, caused by the action of the copper.

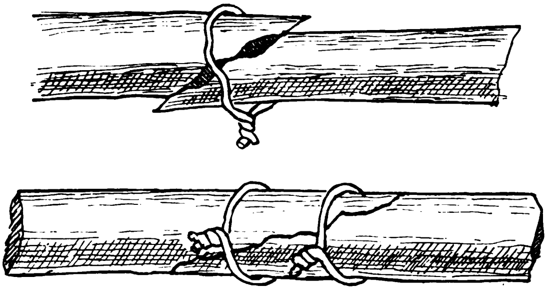

Fig. 98.—Wiring bones by encirclement. (1) In the upper figure the wire is loose and the fragments not adjusted. This leads to chafing against the foreign body, delayed union, and secondary sepsis. (2) In the second figure are shown exact restitution, tight twisting, and efficient fixation.

Soft iron wire is far superior to silver. It is much stronger than either bronze or silver; for example, samples of No. 24 (standard wire gauge) silver, aluminium-bronze, and iron wires had a breaking strain of 31 lb., 44 lb., and 50 lb. respectively, as tested in an engineering laboratory. It is very cheap, and can be easily tin-plated. For all practical purposes the three sizes Nos. 20, 18, 16 (standard wire gauge) will cover all possible requirements, and it is important that the soft (not hardened) wire only should be used, because the latter is difficult to bend and easily breaks when twisted.

The second important point in using wire for bone surgery is that the fragments must be accurately restored to their proper position, or at any rate to a stable equilibrium, before the wire is tightened. This is often difficult. The parts are sometimes brought into approximate position, and then the wire placed as tightly as possible, or actually used as a traction material: when the muscular tension is altered, the badly fitting bone ends become loose, and there is just that loose surrounding with wire which I have already shown to be so inimical to fracture repair (*Fig.* 98).

Again, another error made commonly in the use of wire is to tighten it by twisting. This always makes a weak place at the junction of the last twist with the circular piece, and here the wire often breaks. It is absolutely necessary that the wire be drawn tight enough to allow no movement whatever, and when this has been done a single turn should be taken without relaxing the tension, and after the long ends have been cut off, three further turns are taken in the short ends without any tension at all. If the bone is quite superficial, it is easy, by taking a long piece of wire and holding each end in a handle, to pull strongly upon it and then to twist at the same time; but in some cases, either the bone to be wired lies in the depth of a wound, or else it is desirable that the point where the wires cross should lie deeply buried, and in either of these cases it is necessary to use some special forceps by which the wire may be firmly adjusted where

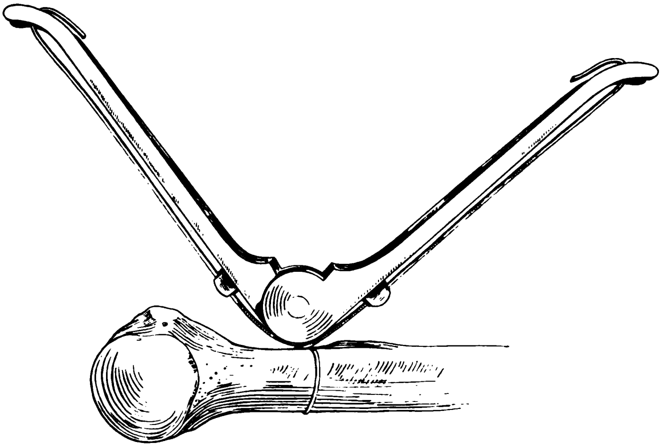

Fig. 99.—Author's wire-tightening forceps. The wire is passed 'round the bone, its ends are crossed, then laid in slots in the sides of the forceps, and turned round the V-shaped ends of the handles. When these are closed together the wire is tightened, and can then be twisted.

it lies buried in the tissues. The action of these wire-tightening forceps is as follows: the wire ends are caught in the handles and drawn upon, when the handles are pressed together, by a force which is twelve times as great as that used by the hand; this force is applied to the tightening of the wire in exactly the right plane (*Fig.* 99). Then, by a single turn of the handles of the forceps the first twist is made. The forceps can now be disconnected, the extra safety twists are given, and the ends cut off and turned down.

If used under the conditions laid down, i.e., strong material, accurate reposition of the fragments before tightening, and firm tightening before twisting, I believe that wire will serve a purpose, in a very restricted number of fractures, unequalled by any other method. Those in which it is especially useful are cases requiring the fixation of small pieces of bone to the main bone from which they have broken, the broken olecranon being the best illustration; suture of the patella in the manner that will be described in detail later; fixation of very oblique fractures of the long bones; and the adjustment of bone grafts.

The only one of these conditions which needs consideration here is that of oblique fracture; the others are specially described in later sections.

Figs. **100, 101** give a good example of an extreme form of oblique fracture; the humerus is split into four pieces. No other method of union in such a case can be compared in efficiency with the use of surrounding wire. Another possible method for oblique fracture is that of transfixing-bolts and nuts, which is only applicable in cases like the tibia or lower end of the femur, when both sides of the bone can be exposed by separate incisions.

In the employment of wire for an oblique fracture, it is most important to have a really efficient extension apparatus—either the clamps that I have described, or else the double transfixion apparatus by which the lower fragments may be strongly pulled upon and rotated at will. As has been said above, the fracture must be completely and accurately reduced and held in this position before the wire is adjusted.

In applying the wire, at least two separate circles are necessary at each fracture. These ought to be no nearer to one another than the diameter of the bone, and a like distance should intervene between each wire and the oblique end of the fracture. In other words, the ideal fracture for wire encirclement is one of the shaft of the bone in which the broken surface is three times the length of the thickness of the bone (see *Fig.* 98, 2). In placing these circles a suitable hook is necessary, which is threaded through the soft tissues behind the bone, keeping as

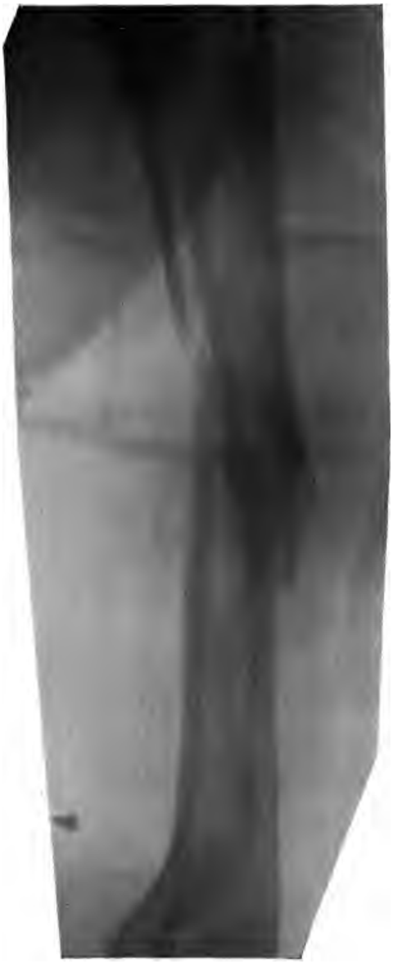

Fig. 100.—The humerus broken in two places, with longitudinal splitting of the central fragment.

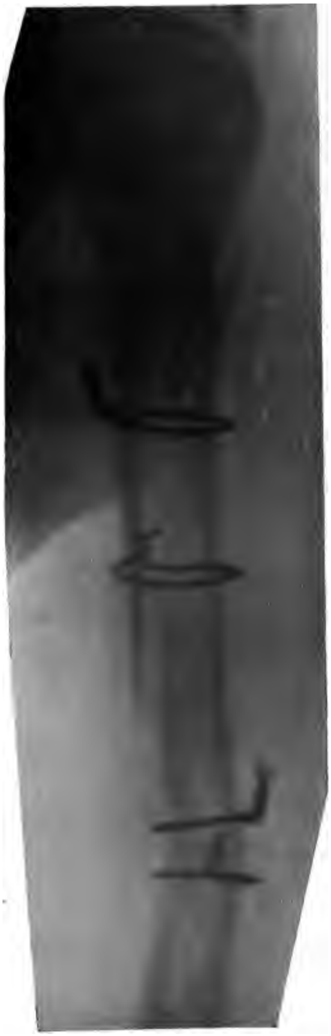

Fig. 101.—Case shown in *Fig.* 100 after treatment by four wire encirclements.

close to the latter as possible, and then withdrawn, pulling the wire in its eye.

If the deep surface of the fracture is readily accessible, the wire is much more efficiently placed in the form of perforating sutures. Here, more than ever, must the fracture be exactly reduced and firmly held whilst the holes are bored for the wire. A motor should always be used if possible, because of the ready way in which it enables the drills to pierce the bones without disturbing the fracture. The drill is passed through the bone and draws back the wire. This being done separately through two different holes for the two ends of the wire, a double suture is thus placed, which is secured by tightening and twisting the ends (*Fig.* 102).

The two great advantages of these perforating wire sutures over wire encirclement are: first, that they do not strangle the blood-vessels round the bone; and next, that by passing through perforation holes they hold the fragments more steadily than is possible by mere tension.

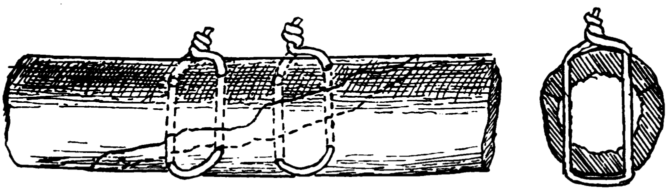

Fig. 102.—Wire sutures applied to bone.

On the Plating of Fractures.

At the present time the operative treatment of fractures consists almost entirely in 'plating'; in other words, in the fixing of metal plates to the outer surface of one aspect of the broken bone. And because this is regarded as the best possible operative method, there is an inclination on the part of many surgeons who have employed it to question the value of operative treatment of fractures in general. The reasons for this doubt are:—

1. In so many plated fractures removal of the plates and screws is required.
2. In the large proportion of cases the plates become loose before firm union has taken place, and in this way deformity occurs in spite of the operation.

3. The method requires just as long and as careful immobilization on splints as if no operation had been performed, so that there is often a stiffness of the joints and loss of function in the muscles, as in the older methods.

There is abundant evidence, however, to prove that the screwing of a narrow flat plate on to the outer surface of a bone is not correct in its mechanical principles, neither is it efficient in its clinical application, and it should no longer be regarded as the standard by which to judge operative methods.

The Lane Plate.—This is a narrow flat plate, varying in thickness from $\frac{1}{16}$ in. to $\frac{3}{16}$ in., and being about $\frac{1}{4}$ in. wide. All the screw-holes are in the same line, the small plates having one hole at each end and the large ones four. The action of such a plate will depend entirely upon the firmness with which it is fixed to the bone. It acts as a splint just so long as it is screwed tightly to the bone. Its narrow flat shape offers practically no resistance to any rotatory force, nor to one which acts parallel to its flat surface. In other words, Lane's plate depends entirely upon its screw fixation. But this is of such a nature that it cannot remain firm for more than a very short time. The Lane screw is of the same construction as that used for wood work and known technically as a 'wood' screw. It differs only from the ordinary pattern of 'wood' screw in having its thread cut right up to the head. Such a screw when used for wood buries its thread in the soft wood substance and in this way it obtains its grip. Even then it will only act efficiently when driven into wood across the lie of the grain, i.e., at right angles to the length of the wood fibres; every carpenter knows that a short 'wood' screw will not hold against any strain when driven into the end of a bar of wood, because it then merely separates the wood fibres and holds only by a frictional grip. But the substance of the shaft of the long bones has no soft fibrous structures, and when a hole is made in its substance into which a 'wood' screw can be tightly driven, the latter cannot bury its thread at all, but merely makes a faint groove in the smooth walls of the hole, in which it holds by friction only.

Fig. 103 shows this quite clearly; the two lateral screws in this specimen had been driven into the bone as firmly as was possible with a large screw-driver, and yet the thread has only cut the shallowest of lines into the bone. The hold of such a screw entirely depends then upon the frictional grip, which is distributed not over a large surface of bone, but merely over the linear spiral surface touched by the edge of the screw-thread. No wonder that the bone rapidly softens before this pressure, and the screw becomes loose.

Moreover, as all the screws are in the same plane, they can only hold the bone by a narrow segment of its thickness. However long such a plate, and however many screws are used in its fixation, the whole structure only holds to a piece of the bone which is the width of one screw. In a femur, for example, 1 in. in diameter, a series of screws $\frac{1}{8}$ in. thick only hold the bone by a twenty-fifth part of its cross-section.

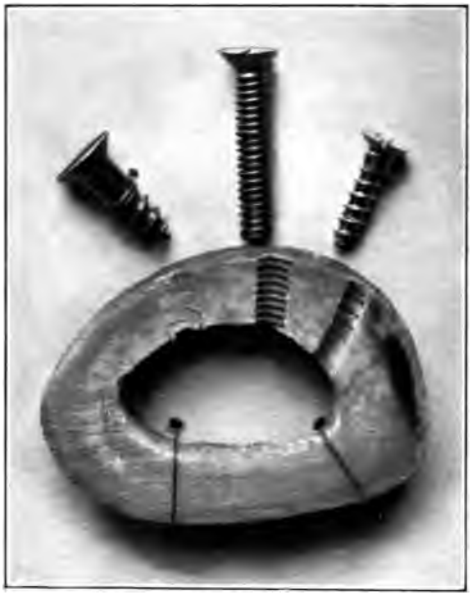

Fig. 103.—Showing the action of 'wood' and 'metal' screws. The bone has been drilled and screwed by three screws: the left-hand one, an ordinary carpenter's screw; the right-hand one, a Lane's screw; and the centre one, a 'metal' screw. The wood screws make only a faint spiral groove in the bone, whilst the metal screw thread lies in a deep slot cut for its reception.

Lambotte's Plates.—Two of the mechanical defects of Lane's plates have been remedied by Lambotte. He uses a curved plate, and a 'metal' screw. Lambotte's largest plate is 6 in. long, about $\frac{1}{32}$ in. thick, and it tapers at each end, the centre being 1 in. wide and curved so as to form a third of a 1–in.

cylinder. It has no less than seven screw-holes in each half of the plate; but these holes are arranged all in the same line.

The use of a curved plate, i.e., a plate forming the segment of a cylinder, is in itself a valuable mechanical advantage. Not only is the plate as a whole more rigid, but it serves to hold the bone against displacing forces acting not only at right angles to the plate but also parallel to it. The chief objection to Lambotte's pattern is that its great width at the line of fracture shuts the bone out from contact with periosteum and soft tissues for a third of its circumference.

The metal-threaded screw was I believe first used by Lambotte; but its advantages have also been pointed out by American writers, notably Gerster and Sherman. When a screw has to be driven into a hard homogeneous substance like metal, it is necessary to cut for it a female screw-thread into which the male screw-thread fits. Now bone is a dense homogeneous substance much more like metal than wood, and therefore a screw used for dense bone ought to be of the 'metal' variety. These screws are made now with slots cut at their points by means of which they are able to cut their own thread in the sides of a previously made smooth hole.

Fig. 103 shows the metal screw in comparison with the wood screw, and it can be readily seen that such a screw will hold because it fits into a socket made for it, and not merely by virtue of the friction between its thread and the bone.

If one makes the experiment illustrated in the figure, and drives a 'wood' and a 'metal' screw into a bone, one will certainly be struck by the fact that when each is in its place, the 'wood' screw is quite tight, whilst the 'metal' screw can easily be rotated with the fingers. At first sight this may seem to contradict what has been already said; but it is not so. The 'wood' screw is merely a spiral wedge driven into a hole and holding by friction for the moment; when the bone yields ever so little, the grip of the screw is lost. But the 'metal' screw holds without any pressure or friction, simply by a number of V-shaped metal tongues fitting into corresponding sockets in the bone.

Lambotte, by the use of his curved plates and 'metal' screws, has very greatly improved the plating method; he dispenses with splints in the after-treatment, and it is very rare for him to have to remove plates afterwards.

But in addition to the two principles of curved plates and 'metal' screws, there are two other details by which the mechanical efficiency of the plate for bone fixation may be greatly increased.

The Principle of Converging Screws.—In all the plates already described, the screws, many or few, enter the bone parallel to each other and usually in the same plane. But if a curved plate be employed and the screws be put in near the alternate edges, then there will be two series of screws converging towards one another, and between them grasping a considerable segment of bone. In fact, the effect produced will be that of two plates fixed both to the bone and to one another, and distributing between them the forces which resist displacement.

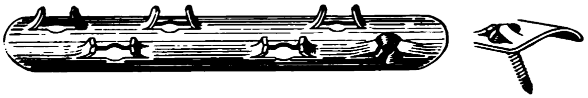

Fig. 104.—Curved plate with flanges for fixing the screw-head. This action is shown in the right-hand figure.

The Fixing of Screws to the Plate.—When a plate is screwed to the bone tightly in the ordinary way, either by a 'wood' or a 'metal' screw, the firmness of fixation depends upon the screw pulling the plate towards the bone and pressing against its own socket in so doing. Now this firmness holds only while the bone remains dense and hard so as to afford a grip to the screw. When the bone softens under pressure the tightness of the screw and the fixation of the plate are lost, and the 'wood' screw will come out soon and the 'metal' screw much later. But if converging screws are used, this principle of the screw pulling tightly against its own thread-socket may be abandoned. The screw may instead be threaded into the plate, and there fixed by the grip of metal against metal in such a way that it never can become loose from the plate. In applying this principle, the plate must be firmly clamped against the bone, plain holes being made into the latter by a drill which does not touch the thread of the holes in the plate. The self-tapping screws are

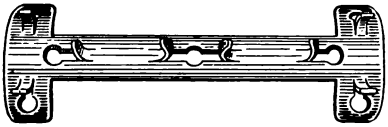

Fig. 105.—A plate with two T-shaped ends which cover one-fourth of the circumference of the bone.

now driven into the bone and screwed tight. The grip of the screws will then be between the screw and the plate, and not between the screw and the bone.

But there are two difficulties in carrying out this device of threading the screws in the plates. One is that the plate must be at least $\frac{1}{8}$ in. thick to carry sufficient screw threads, and this makes it somewhat clumsy and bulky for a small bone. The other is that the plate has to be firmly clamped against the bone whilst the screw is being inserted, otherwise the screw will separate the plate from the bone.

These difficulties have led to the adoption of a different method of fixing the screws to the plates. *Figs.* 104, 105 show small plates only $\frac{1}{16}$ in. thick, the holes for the screw-heads being flanked by little upstanding flanges of metal. When the screw has been driven into the bone and holds the plate firmly, the flanges are turned down over the screw-head with a pair of pliers.

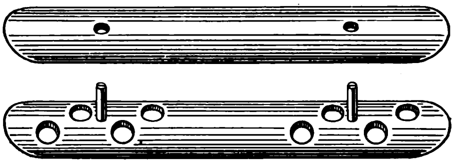

Fig. 106.—Double curved plates. One serves to secure the heads of the screws in the other.

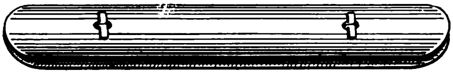

Fig. 107.—The double plate adjusted ; the screw heads lie fixed between the two plates.

Stronger plates $\frac{1}{8}$ in. thick are made in two pieces, the inner bearing screw-holes and upstanding split-pins. This is fixed in place by converging 'metal' screws. Then the outer section of the plate is fitted over the first ; it has no screw-holes, but merely holes to take the split-pins. The latter are bent out and hammered down, and the whole then forms a solid plate $\frac{1}{8}$ in. thick, the screw-heads being firmly held between the two sections of which it is composed (*Figs.* 106, 107).

The four principles which should be observed in screwing plates to bones are these :—

1. The plates should be curved.

2. The screws should be 'metal'-threaded and self-tapping.
3. The screws should be applied in converging directions, and not all in the same plane.
4. The screws should be fixed to the plate as well as threaded in the bone, and it should be the grip between the metal screw and the metal plate which secures the screw from becoming loose.

The plates I have devised, which carry out all these principles, are described in detail in the accompanying figures, and what has already been said about their application makes further description of technique unnecessary. The forceps used for driving the screws in is shown in *Fig.* 108.

Such a plate, when placed in position and attached by eight screws, constitutes an eight-pronged solid claw, the prongs of which, being fixed in the dense bone at wide intervals and at converging angles, take such a firm grip of the latter that nothing short of the disintegration of the bone can bring about displacement.

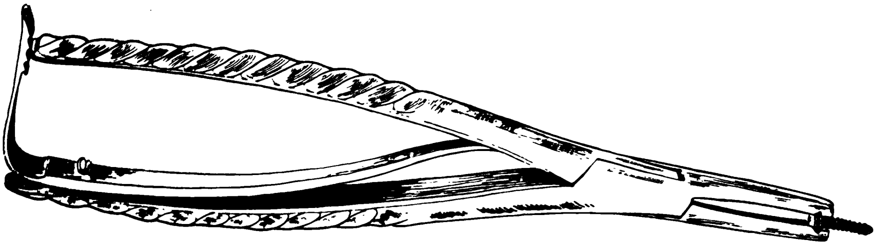

Fig. 108. -Author's forceps for driving in Sherman's self-tapping metal screw.

Plates applied by Transfixion.—If the bone to be fixed is in such a position that three of its surfaces can easily be exposed without serious damage of the soft parts, then it can be transfixed, and in this way a plate can be applied to its surface, either on one or on opposite sides, very simply and firmly.

For small bones, e.g., the lower end of the ulna, I have used the same method as in the lower animals, viz., the fastening on of the plates by means of split-pins $\frac{3}{32}$ in. in thickness and 1 in. long (*Fig.* 109).

Here, too, an advantage is gained if instead of all the pins lying in the same plane, they are placed in converging series which hold different diameters of the bone and so greatly increase the rigidity.

Bolted Plates.—In the case of larger bones and those which have to bear much strain, the ideal method of fracture fixation is the application of opposite plates, fixed to the bone by two bolts above and two below the fracture, piercing the entire thickness of the bone.

This is the method which would be chosen by an engineer in the repair of a broken rod. Curved plates on either side, bolted together, leave the broken bone stronger after the operation than it was before the fracture.

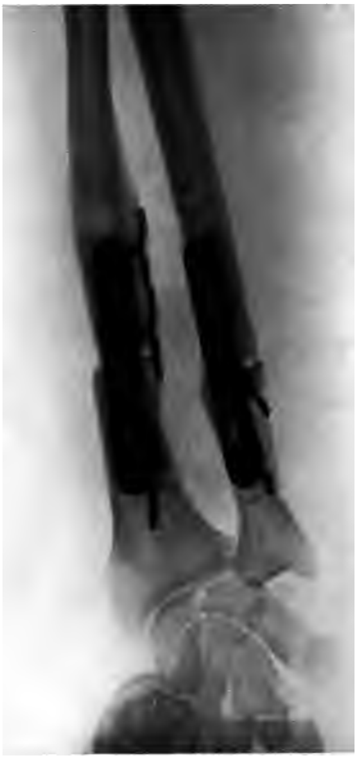

Fig. 109.—Fracture of radius and ulna treated by plates secured by split pins. A year later the patient had full functional use of his hand, with full supination, the plates being still in place.

The main difficulty in fixing the two opposite plates by transfixing-bolts is so to drill the holes that the bolts passing through one plate will emerge at the proper holes in the other.

I have used various types of drill-guide for this purpose quite successfully, and *Fig.* 110 and several others show steel plates thus secured in position. But I have come to the conclusion that the manipulations necessary for this manœuvre make the operation too tedious, and that no one could carry them out without considerable practice. I have therefore now adopted a much simpler plan. The pair of plates to be applied consist of a steel plate, drilled and countersunk for the bolts, and a plain plate of the same size, made of duralumin. This metal has almost as great tensile strength as steel, but it is quite soft for drilling.

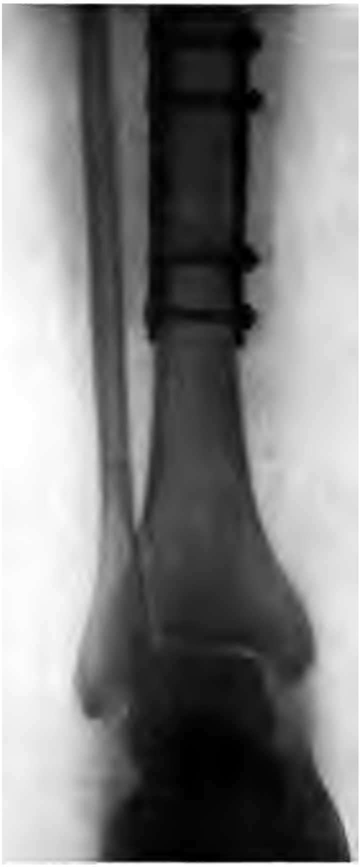

Fig. 110. Fracture of tibia treated by bolted plates.

The plates are put in position on the bone and then clamped by an ordinary Lowman's clamp, or by a special clamp which bears four little teeth fitting into holes in the plates, so that the latter are fitted on to the clamp, which is then adjusted over the fracture and screwed up tight. Holes are then drilled through the bone through the bolt-holes of the steel plate and made to perforate the duralumin plate opposite. The holes in the latter are countersunk by a reamer, the bolts are put through, the nuts adjusted, and the superfluous ends cut off.

The bolts used are $\frac{1}{8}$ in. thick, of soft iron, silver-plated. They can be readily cut by wire-cutting pliers. The head of each bolt is cut for a screw-driver, and the same applies to the nuts, which have a milled edge for rapid adjustment and a cut for a tubular turn-screw.

For drilling the holes in the bone in this and all other methods, I would again urge the great advantage of using a motor-driven drill. Not only is the surgeon spared the fatigue of hand drilling, but he is able to use his muscle sense in the accurate guiding of the direction of the drill. And most important of all, there is none of that jerky movement, inseparable from the use of a hand bradawl, which is very liable to displace the plate or the fractured bone ends.

Where the motor is not available, one of the multiplying drill-braces is a very fair substitute.

I would lay stress upon this point of an efficient drilling machine, so much as to say that without it it is useless to attempt to carry out properly the application of either the plate with converging screws or the bolted plates. One more word may not be out of place here on the subject of proper selection of plates, screws, and drills. In order to carry out a neat operation and do good work, everything must accurately fit. It is not enough to have a large stock of material, and trust to finding everything at the moment of the operation.

First, the *x*-ray picture must be studied and the type of operation decided upon. Then plates of the proper size are to be prepared beforehand, and with them the screws or bolts, and the drills of the right size for these. It is not enough to have the principles of the operation correct, unless it is recognized that one of these principles consists in the most minute fitting together beforehand of all the parts of the machinery necessary for the operation. I would go further, and say that no surgeon is justified in doing one of these complicated bone operations until he has taken the trouble to work it out in every detail upon the dead body, or at least upon the dry bones.

The Closure of the Wound.—About this there is not much to be said. The clamps are removed, the retractors slipped out, and a last careful search made for bleeding points, which are dealt with. Then the soft parts are brought together by separate catgut sutures as carefully as possible. First, the deep layer of muscle, with the periosteum, is sewn over the bone so as to enfold the fracture area and wrap round the plate or wire. Then the deep fascia is united, and then the skin. Michel's clips are used for the latter, reinforced by a few silkworm gut sutures if there is much tension.

No drainage ought ever to be employed, or at the utmost it ought to be limited to a strand of silkworm-gut ligature which is removed with the first dressing.

As a rule no splint is to be employed, except for a few hours to guard against post-anæsthetic restlessness.

After-treatment of Operation Cases.—For the first week rest, with the joints in a position of semiflexion, is the rule. On the sixth day after operation, the clips are removed from the skin and a strip of gauze is fixed over the incision with collodion. From this time onwards the limb is treated every day by light stroking massage and movements of the joints. In fact the case is conducted exactly on the lines laid down in Chapter II.

In the case of the arm, there is no restriction placed on the movements, except that of the patient's own instinct. He is, on the contrary, encouraged to carry out regular movements systematically.

In leg fractures, the patient should be out of bed within a fortnight of the operation, walking on crutches, exercising all the joints of his leg, and encouraged to put his foot to the ground just as soon as he can do so without causing pain. In a period varying from a month to six weeks after operation he ought to be able to discard the crutches, and from this time onwards his progress will be conditioned chiefly by his own will and wish to return to work.

CHAPTER VII

ON THE OPERATIVE TREATMENT OF SPECIAL FRACTURES

THE principles already laid down for the operative treatment of fractures require the careful consideration of details for their proper application. For not only is the structure of every bone different, but also there exist wide differences in the anatomical relations of each bone, and most important of all, there are scarcely two fractures even of the same part of the same bone precisely alike.

Each case therefore has to be studied and treated upon its own merits, and if operation is deemed necessary, it is often better to have the suitable apparatus specially made, rather than attempt to adapt some stock apparatus to every case. This remark applies particularly to old fractures in which mal-union or non-union is present and in which there is no hurry to act at once.

It must be understood that in the present chapter there is no attempt made to discuss which cases require operative treatment, but merely to indicate the anatomical and mechanical conditions which accompany each.

FRACTURES OF THE LOWER JAW.

In one respect the lower jaw is badly adapted for the operative treatment of fractures, and that is that the worst type of break, which otherwise would require operation, is usually complicated by a wound communicating with the oral cavity. But in all other respects the anatomical and mechanical conditions for fixation of the jaw are ideal. The bone is stout and dense; it can be approached on both surfaces; it is very vascular; healing occurs readily; and there is no special difficulty in reducing the displacement.

Non-operative Methods of Treatment.—A few words are first necessary about the many and ingenious methods which are detailed in text-books and monographs. An epitome of all of them would fill a good-sized volume.

The majority of these have been invented by dental surgeons, and in the era long before operative treatment of fractures in general was understood. They are of three kinds: (1) The simple fixation of the mandible against the maxillæ by bandages, moulded splints, or with the interposition of a wedge-shaped interdental splint. Except for fractures with little or no displacement, or as a preliminary to other treatment, such methods are to be dismissed on the score of inefficiency. (2) The tying of the fractured bone together by means of wire splints fitted round the teeth. These methods are only possible when the teeth are in exceptionally perfect condition, and they run a severe risk of injury to the teeth—structures which quickly become loose when utilized as fixation apparatus. (3) There are many elaborate mechanisms by which the inner and outer surfaces of the jaw are clamped together. This is certainly the worst of all systems, because it is not only the most uncomfortable and unsightly, but it is dependent upon pressure on the teeth, which become loose, and upon the skin, which becomes sore.

The Problem of the Oral Wound.—In all bad cases, except perhaps those of the ramus, the fracture communicates with the mouth, and for the moment is therefore septic. As a first preliminary, therefore, the mouth should be cleaned, if necessary under an anæsthetic. All bad teeth are to be removed, and septic dental conditions remedied. The jaw is put into good position, and to its outer surface is moulded a poroplastic splint which is kept in place for about a week or ten days. Every day and at frequent intervals the mouth is washed out with Condy's fluid, especially before and after food. At the end of this time the mouth wound will usually be healed, and the jaw can be safely exposed from outside.

Anatomical Considerations.—The whole of one side of the lower jaw can be exposed by an incision which skirts just below its margin and turns up behind the angle. The skin ought to be freely reflected upwards and downwards from the incision. The only structure to be carefully preserved is the inframandibular branch of the facial nerve, which ascends over the jaw to the muscles at the angle of the mouth. This should be dissected out and turned upwards with the upper skin flap, dividing if necessary the branch to the platysma, which is of no importance.

If the fracture is in the posterior third of the jaw, the facial vessels must be divided between two ligatures and the insertion of the masseter muscle turned upwards. The same treatment is necessary for the lower muscles situated at the angle of the mouth. In general terms, the outer surface of the body of the jaw and the lower part of the ramus are exposed by turning up the periosteum of the bone with all the overlying soft parts.

The deep surface is exposed by merely pulling down the submaxillary salivary gland, and turning up the periosteum with the superjacent internal pterygoid muscle.

It is not often necessary to make such a complete exposure of the bone as is here indicated, but a free skin incision with a posterior vertical limb, and division of the facial vessels, will greatly facilitate exposure of even a small part of the bone.

The Fixation of the Bone.—

a. Adjustment of the Fracture.—In the case of the jaw it is not the gross adjustment, but the accurate fitting together of the broken surfaces, which gives difficulty. This can only be overcome by patience and by the removal of broken spicules of bone or of fibrous tissue which lie across the gap. It is important in this manipulation to act with the greatest gentleness, and to avoid pulling the bones apart in such a way as to re-open the wound into the mouth.

b. Wiring.—The jaw is certainly one of the bones in which the efficient use of wire gives good results, providing that it is only used in suitable cases. The chief factor which determines this is the accuracy with which the fracture can be reduced. If the parts of the bone have suffered no loss, and if there is no comminution, so that the broken surfaces can be as accurately fitted together as is the case in a bone outside the body, then wire is ideal both in its simplicity and efficiency. But if reduction is not perfect, or if by reason of splintering the fragments come together so as to allow of a little play between them, then it will be better to apply a plate. Not less than two wires should be used, and the No. 16 iron wire is the best size and material. The bone is held in powerful bone forceps, and two holes are drilled opposite one another on each side of the fracture, just above and below the thickest part of the body of the jaw. Each drill-hole is countersunk by a burr. When all four holes are drilled, the wire is inserted. This is done by passing the two ends of a piece of wire from within outwards through the bone. In case of the upper holes being somewhat inaccessible and difficult to thread with the wire, a hollow wire guide is passed through the hole from without, the end of the wire put into this, and then the wire guide used to pull the wire through. This is much better than the use of drills with perforated ends to withdraw the wire. Such drills will not take anything but quite fine wire, unless they are very large; and the act of withdrawing the wire, which doubles up in the eye of the drill, is apt to be accompanied by a jerk which disarranges the fracture. It is very tempting to pass the wire from without inwards, and to twist the ends on the inner side; but I think that this is so difficult to do accurately when the wire twist is practically out of sight, that it is better to have the ends on the outer surface where they can be properly manipulated.

When both wires are in position, and before they are twisted, a final adjustment of the fracture is made. One wire has its ends crossed and pulled upon to hold the bones together whilst the other is being adjusted.

It is worth while to prepare a bed for the outer part of the wire loop and twist, so that when the overlying soft parts are replaced there may be no sharp projecting wire ends to cause pain or irritation. For this purpose a groove is cut in the bone from one hole to the other, and at one point of the groove a hollow is made with a burr for the twisted end.

The ends of the wire are then pulled upon at right angles to the surface of the bone, and with a pair of flat-bladed forceps the deep part of the wire loop is made to lie close against the bone so as to allow no slack. Then the wire is tightened and accurately twisted, cut off so as to leave three whole twists, and the twisted part turned down into the hollow made for it. The object of countersinking the outer ends of the drill-holes in the bone is to prevent the turning of the wire at a sharp right angle at these points. The wire being curved and not kinked can be more tightly adjusted.

The second wire is then adjusted in the same way as the first, and when this has been done the jaw ought to be absolutely rigid.

c. Plating.—It is quite easy to put on a short plate of the Lane type on the outer surface of the jaw; but this will certainly not hold tight for very long. Also a curved plate with screws locked into it may easily be applied, but such a plate will cause an ugly thickening on the outer surface of the jaw, a thickening which will be liable to increase in time as periosteal new bone is heaped up upon it. For these reasons I think that the plate should be applied to the inner surface of the jaw, and should be fixed by bolts and nuts.

The plate I use is $1\frac{1}{2}$ or 2 in. long, $\frac{1}{2}$ in. wide, and $\frac{3}{32}$ in. thick, and made of duralumin. The fracture having been adjusted, the plate is placed on the deep surface of the bone and held there by catch forceps, which also grasp and hold the bone. The holes are to be drilled from without inwards, first through the bone and then through the plate, two holes being placed on each side of the fracture. After each hole has been made, the outer end is countersunk by a burr, and a screw is put through plate and bone and held in place by means of conical nuts. Then the ends of the screws, which are $\frac{1}{8}$ in. thick, are cut off flush with the nuts after the latter have been tightened up so as to make the thin flexible plate mould itself accurately against the deep surface of the bone. When this has been properly done, the nuts lie buried in the bone, the contour of which is quite even, and the soft parts being sutured in place, there is no palpable thickening or irregularity left, and the whole jaw is absolutely strong and rigid.

The use of a plate in this fashion is certainly the most satisfactory way of dealing with a fractured jaw, especially in those cases where some time has elapsed since the accident, and in cases where there has been any splintering of the bone, which prevents a rigid readjustment of the fracture by wire.

Comminuted Fractures of the Symphysis.—The present war has made us familiar with gunshot wounds of the chin, which not only take away the soft tissues but shatter the jaw and the teeth. In cases where the remainder of the teeth are quite sound and firm, a temporary dental appliance can be put into position to keep the jaw from falling together until the wound is sufficiently healed to permit of a more permanent dental plate. But those cases which have come under my own observation have either had all the lower front teeth loosened, or have had no lower teeth which afforded a secure hold even for a temporary apparatus.

The débris of teeth must be removed, but however comminuted is the jaw, no fragment should be taken out that can possibly be saved. For the first week attention is to be solely directed to the cleaning of the wound—until this has taken on a granulating surface and is free from sloughs. Then a strut is to be inserted in the floor of the mouth which will hold the two halves of the jaw in place whilst the symphysis is healing.

I have used with excellent result a simple bolt provided with four sets of nuts and washers, one on the outer and inner surfaces of each side of the jaw. This was not only rather difficult to apply, but the presence of the straight rod below the muscles of the floor of the mouth pressed the latter up so much as to greatly impede both speech and swallowing.

It is better therefore to use a curved rod, which is made to lie comfortably below the floor of the mouth, and can be adjusted to any breadth between 2 in. and 3½ in. It is made in two halves. Each half terminates with an ⅛-in. screw which goes through the body of the jaw and is firmly fixed there by a nut and washer. The middle portion of each half is flat, ½ in. wide and $\frac{1}{16}$ in. thick, and when the two halves have been adjusted to the correct breadth they are screwed together. The proceeding of most importance in the application of this or any similar transverse jaw bolt is the boring of the holes in the two sides of the jaw. This should be done by a long ⅛-in. drill, right through from one side to the other, the jaw being held in correct position against the upper teeth whilst this is being done. If the holes are drilled thus in the same line when the fragments are in their proper place, these will adjust themselves correctly when the bolt is in position. The incision for this operation is a ∩-shaped one, following the lower border of the jaw just on its inside. This allows access to the outer surface of the mandible for boring and for adjusting the nuts, and on turning back the skin flap it permits the apparatus being adjusted below the muscular floor of the mouth.

FRACTURES OF THE CLAVICLE.

As far as my experience is concerned, fractures of the clavicle are very satisfactorily treated by non-operative methods. I have never yet seen a broken clavicle which in my opinion required open treatment, although I do not deny that such a case may be possible.

If the bone is obliquely broken and much displaced, one of the sharp ends may injure the subclavian vessels or the brachial plexus. The operation will then be undertaken primarily for the suture of these structures, but the broken bone invites fixation at the same time. Efficient *wiring* will probably be the best operation, as such a fracture is likely to be very oblique.

In uncomplicated cases gross displacement can always be reduced by any system which draws back the shoulder and lifts up the weight of the arm. Anything short of gross displacement is of but little moment as regards the use of the arm. It would be unreasonable to operate upon the clavicle in order to prevent a callus swelling, because the scar is much more unsightly than the callus and much more permanent.

The most fruitful cause of loss of function after fracture of the clavicle is undoubtedly long immobilization in strapping and bandages. Indeed, the only cases of this injury with lasting disability which I have ever seen (for insurance companies) are patients whose arms have been kept fixed to their sides for three, four, or even six weeks.

As has been said above, only two things are necessary in putting up a fractured clavicle—viz., to keep the shoulders back and the weight of the arm supported. This is really the application of extension in the long axis of the clavicle. The pulling back of the head of the humerus and acromion draws the outer fragment outwards and backwards. There are various ways of doing this. One of the simplest is by means of a thin well-padded splint across the back, to which each shoulder is strapped (*Fig.* 111). The forearm is held in a sling which securely supports the elbow. ' Massage ' is indicated from the very first, and this appliance is especially convenient, because the whole limb is left free for stroking and for movements. Abduction

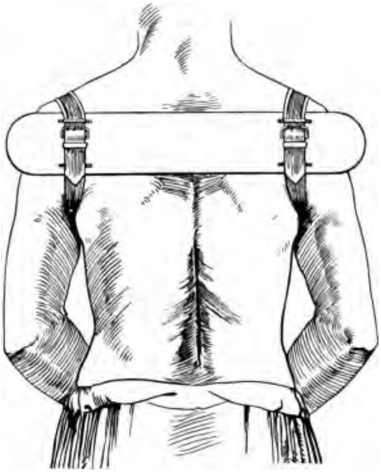
Fig. 111.—Splint applied for fractured clavicle, viewed from behind.

of the shoulder-joint is the movement to be most carefully used, and it is an excellent thing to make the patient sleep with a firm square pillow in the axilla after the first week, so as to keep the humerus away from the side.

After ten days the splint is removed daily for massage, and is left off altogether at the end of three weeks.

FRACTURES OF THE HUMERUS.

The Upper End.—Fractures of the upper end of the humerus do not often require open operation. They are usually incomplete or subperiosteal, and even when complete there is not much displacement. All such fractures unite rapidly, and if treated by 'massage' and mobilization will give better results than by any other method.

Separation of the Anatomical Head and of either of the Tuberosities are the chief intracapsular lesions to be considered as requiring operation. For all these there is only one practical and efficient method, and that consists in nailing or bolting.

The first question which arises is that of the adequate exposure of the injured bone. The head of the humerus lies so deeply covered by muscles, that it is difficult to get at, and impossible to deal with properly, unless this is ensured. The only adequate method consists in the first stages of an operation for excision of the head of the humerus through an anterior incision.

A vertical incision down the middle of the front of the arm exposes the interval between the deltoid and the pectoralis major. The cephalic vein lying in this is cut or drawn aside, and by retraction of the muscles named, the capsule of the joint is seen, with the long tendon of the biceps running down from it. These fractures usually involve an injury to the capsule, and therefore there need be no hesitation in dividing this freely along the channel of the biceps tendon, hooking the latter inwards, and clearing out all blood-clot, together with any small fragments of bone. If there has been much comminution, especially in elderly patients, it is certainly much better to be content with removal of loose fragments, an accurate hæmostasis, and suture of the capsule. We have to bear in mind that the great danger of injuries to the head of the humerus is stiffness rather than weakness, and it is better therefore to remove all small pieces, even if these constitute the whole of the articular head and both tuberosities, and trim off the end of the shaft, rather than to attempt an elaborate reconstitution of the bone, with the danger of getting a big mass of callus with adhesions. If this trimming has to be done, it is generally easy to find some flap of fascia and muscle to stitch over the bone to prevent adhesions. It is of course important not to neglect examination of the glenoid cavity of the scapula, with similar removal of loose bone from that surface.

But when there is a clean separation of one or two large fragments of bone, usually the anatomical head or great tuberosity—particularly in young patients these should be preserved and united to the shaft. In the case of the head of the bone, it is necessary temporarily to disarticulate the joint in order to fix the fragment properly. This is done by separating the muscles attached to the two tuberosities, together with the capsule of the joint, from the bone. In doing this the cutting should be made right down on the bone, so that muscles and capsule retain continuity with the periosteum of the shaft. By this means a rapid re-attachment of these structures may be assured afterwards.

An ingenious suggestion has been made for nailing the head of the humerus in its place without opening the joint. This is done by driving a long nail vertically downwards in the axis of the humerus through the acromion or through the acromio-clavicular joint. This method has nothing to recommend it except its simplicity. In the first place, it ignores the cardinal difficulty of the displacement of the fragment. If this is not displaced the operation is unnecessary; and if it is displaced the nail will merely fix it in a wrong position. Further, the nail can only take a hold on the shaft through very open spongy bone, and it runs on into the marrow cavity.

If it is necessary to operate on the separated humeral head, this can only be done by full exposure in the manner described. When the upper end of the humerus has been brought out of the wound, the separated head is recovered from the depths of the joint and fitted to it exactly. Here it is fixed by a square ivory nail long enough to come right out below the great tuberosity. It is best to make a hole for this nail with a bradawl. The head of the nail is driven in flush with, or below, the articular surface, and the projecting end cut off level with the outer surface of the bone. If the humeral head is found still to be insecure, the nail is removed, and for it is substituted an iron bolt with a nut, which gives a perfectly secure hold.

In the case of separation of either tuberosity, it is not necessary to disarticulate the joint. After the capsule has been opened and the débris cleared away, the region of the small tuberosity is brought into the middle of the wound by external rotation of the arm, and that of the great tuberosity by internal rotation. The separated tuberosity is then secured in place by a square ivory nail, after boring.

Each of these operations is concluded by replacing the biceps tendon, suturing the capsule of the joint, and then the skin, after the most careful scrutiny of the hæmostasis. The arm should be put up at first in full abduction, the forearm and elbow tied to the head of the bed. It is a great advantage to maintain this position for a week or ten days whilst the wound is healing. It is wise to secure full abduction from the very outset, because adduction can easily be recovered, whilst it is common knowledge that once the shoulder is fixed with the arm against the side it is very difficult to restore full abduction.

Fractures of the Upper Third of the Shaft, including the Surgical Neck.—This region has this anatomical peculiarity, that it is not possible adequately to expose more than one aspect of the bone. The great vessels and nerves are on the inner side, and moreover the axilla forms a most inconvenient aspect of approach. When exposed from in front, the tendon of the great pectoral muscle prevents access to the inner surface of the humerus. And the posterior route is impossible because of the circumflex nerve running to the deltoid muscle. Therefore we are limited to an anterior incision between the deltoid and pectoral muscles which exposes the outer surface of the humerus below the great tuberosity.

For this reason operative measures here must be limited to the use of an intramedullary peg or a single plate. The peg is only suitable if the fracture is two inches or more below the surgical neck. The technique of its use is described in the next section.

If a plate is used, some type of rather thin curved plate with converging screws should be chosen, and those figured will give a good idea of their character.

Fractures of the Middle Third of the Shaft.—Apart from special complications, such as injury to the musculospiral nerve, the chief indication for operation is a transverse fracture which cannot be properly reduced. The cause of this difficulty consists in the interposition of soft parts between the bone ends, and leads often to non-union or delayed union. Oblique, fissured, and subperiosteal fractures all heal rapidly under massage and mobilization, and in these there is nothing gained by operating. Comminuted fractures do well by extension methods.

Exposure of the Fracture.—The middle of the humerus is readily approached on either the outer or inner aspect. A vertical incision down the anterior margin of the deltoid exposes the interval between the deltoid and biceps muscles, and the anterior and outer aspects of the bone are reached by retracting these structures. On the inner aspect of the arm, an incision along the inner border of the biceps lays bare the deep fascia covering the great vessels and nerves. The fascia is incised and the vessels retracted backwards, exposing the inner and anterior surfaces of the bone partly covered by the coracobrachialis muscle.

It is not possible to lay bare a large area of bone in the mid-part of the humeral shaft by mere muscle retraction, as it is in the case of the femur or tibia. The deltoid, brachialis anticus, coracobrachialis, and triceps are so attached to it that it cannot be widely exposed without separating their attachments. For this reason the plates used must be narrow, or the fixation must be by intramedullary pegs.

If plates are used, it is best to employ a single bolted plate (3 in. by $\frac{5}{16}$ in.) placed just in front of the insertion of the coracobrachialis or just behind that of the deltoid, and the manipulations should be done through two opposite incisions.

Fractures of the Lower End.—Fractures of the lower end of the humerus are of such great variety and complexity that it is difficult to formulate any simple rules to guide the selection between operative and non-operative treatment. In the first place it must be granted that all gross displacements which cannot be reduced with the aid of anæsthesia or 'massage' require open suture. But there are two classes of cases in which there is great difficulty in deciding on the best treatment.

1. There are cases in which small pieces of bone are torn off or fissured without altering the line of the elbow-joint. Such injuries are the common results of dislocation. For example, it is very common for the forearm to be partly dislocated outwards, and this tears off the internal epicondyle from the humerus. Reduction of the dislocation may leave the fragment of bone inside the joint, the capsule of which has necessarily been torn. If this is left, the final movements of the joint may be much impaired. There are also of course many other injuries of a

similar nature with a severe joint traumatism accompanied by the separation of a little piece of bone. A further difficulty is caused by the fact that in children, in whom these injuries are common, the separated fragment consists so largely of cartilage that it affords a very minute shadow by the *x* rays. I believe that the majority of these cases will give perfectly satisfactory results if treated by 'massage' and movements. But it is most important that this method should be rightly employed according to the principles laid down in Chapter II. The arm is put up in full flexion and supination, and each day is lightly stroked and moved very gently without causing pain. Any attempt to produce full movements by force will only increase effusion into the tissues, and will defeat the whole object of the mobilization.

If the case responds to this treatment, the elbow ought to be almost well within three weeks of the accident in regard to range of movement, though not in strength. If at the end of two or three weeks there is still much limitation of movement, then it is much better to open the joint and remove the separated fragments of bone.

2. The other class of case which involves much hesitation in deciding as to treatment, is the comminuted fracture seen by the surgeon at some period after the injury, where union of the fragments has occurred without gross deformity, but in which there is great limitation of movement. Is it better in such a case to persist in various movements, active and passive, for a long time, or to attempt to hasten matters by operation ? I do not think it is possible to lay down any definite rule in such cases, but the following considerations should help in a decision. The three factors which justify the hope of recovery without operation are—youth of the patient ; the absence of serious anatomical deformity, e.g., partial lateral dislocation or presence of bone fragment in the joint ; and the possibility of restoring full movement without great force or any tearing when the patient is anæsthetized.

The factors which call for operation are—adult age of patient; limitation of joint movements even under an anæsthetic; and above all, the presence of anatomical deformity which is amenable to operation, particularly displacement of particles of bone and the existence of callus excess. The operation in such cases would consist in removal of all outstanding or loose pieces of bone, and of chipping off masses of callus, especially those which lie in and under the brachialis anticus, and have been called myositis ossificans. The soft parts are very carefully sewn over the raw bone, to limit as far as possible fresh callus formation, and the arm is put up in full flexion. In some cases it is extension which is limited, the forearm being brought up with a jerk against some solid resistance. This is due to the filling of the olecranon fossa of the humerus with callus. It is best treated by removal of the tip of the olecranon process. Any attempt at gouging out the olecranon fossa is not only very difficult, but soon is followed by renewed callus deposit.

ANATOMICAL CONSIDERATIONS.—The lower end of the humerus is very closely surrounded by muscles, vessels, and nerves, so that it is only accessible to a very limited extent.

In front it is covered by the brachialis anticus very closely, and over this lie the biceps, the brachial artery, and the median nerve. Behind is the triceps muscle and the olecranon process. On the outer side and rather in front lie the extensor and supinator groups of muscles with the musculospiral nerve, and on the inner the pronator and flexor groups, the ulnar nerve being posterior. This arrangement of the soft parts makes it essential to expose the bone laterally, and by making incisions from in front of the epicondyles upwards, the supracondylar ridges of the bone can be exposed, together with the parts of the anterior surface adjacent to them. The musculospiral nerve is retracted with the muscles arising from the external epicondyle. The lower end of the humerus is so shaped that any transverse drilling is very liable to enter the joint, in the coronoid or olecranon fossa. In order to transfix the articular part of the bone so as not to interfere with the joint, the drill must pass from the middle of the inner surface of the trochlea to the middle of the outer surface of the capitellum, the hole being in both cases just in front of the respective epicondyles. This line not only avoids the joint fossæ, but it lies in the centre of the articular masses, so that any transfixing-bolt will hold the fragments together with great mechanical efficiency.

There is another method of approaching the lower end of the humerus which is of great value when the fracture is so complicated that the fragments cannot be accurately restored to position through lateral incisions. This consists in cutting through the olecranon. If this be done by means of a fine fret-saw in a >-shaped manner, it can be restored by a wire suture so that no disability results, and the exposure of the joint surfaces is most excellent.

Technical Considerations.—In operations on the elbow-joint, it has to be borne in mind that free mobility is the great object to be attained.

To get a perfectly mobile joint, it is necessary to make an accurate restoration of the articular surfaces, and to fix the fragments in such a way that there will be no callus excess in the process of repair. Therefore accuracy and efficiency in fixation are essential, and mere wiring is quite unsatisfactory.

Nailing or Screwing.—This is a method which has a limited scope, and I think ought generally to be replaced by bolting. It is employed when a single piece of bone has been split off. This may be either epicondyle, usually the internal, or the capitellum with the external epicondyle. The fragment is replaced, and a long screw used to fix it. But this will only run into cancellous bone, on which it has but little hold, and a square ivory nail will be better. Such means of fixation, however, are very apt to allow a little movement between the fragment and the main bone when exercises are undertaken, and this will be liable to cause outgrowths of callus.

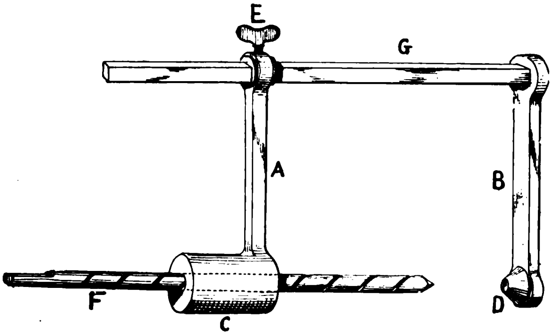

Fig. 112.—Drill-guide for making a hole through corresponding points on the opposite sides of a bone. A, Metal bar movable on the bar G, where it can be fixed at any point by the screw E. B, Another bar fixed to G parallel to A. C, Metal cylinder ½ inch long, perforated by a hole which just takes a twist drill. D Conical face at the end of B, which fits into the countersunk hole of a plate. The action of the guide ensures the drill F perforating the bone at the point D.

Bolting.—This ought to be the method of choice in all bad fractures of the lower end of the humerus. The bone is first exposed by the lateral incisions described above, and if there is any doubt as to the accuracy with which the fragments can be fitted together, a transverse incision across the base of the olecranon is made, forming a U-shaped skin flap. If the *x* rays have made it quite clear that the articular end of the humerus is divided into only two fragments, the posterior incision is not necessary; but when there is further comminution, the division of the olecranon is of great assistance, because only by this means can a good exposure of the joint be made, small fragments of bone removed, and the line of the articulation be perfectly restored.

When the broken bone has been pieced together, the whole lower end is transfixed. In order to make the drill-hole enter and leave the bone at exactly the desired points, a special clamp drill-guide is very useful (*Fig.* 112). The screw points of this are driven into the bone just in front of the epicondyles, and if the drill is then passed into the axis of one hollow screw it will emerge at the other. The drill is withdrawn and the drill-guide removed; the fragments are then firmly held in place and a long bolt inserted. At this point it is necessary to consider how the

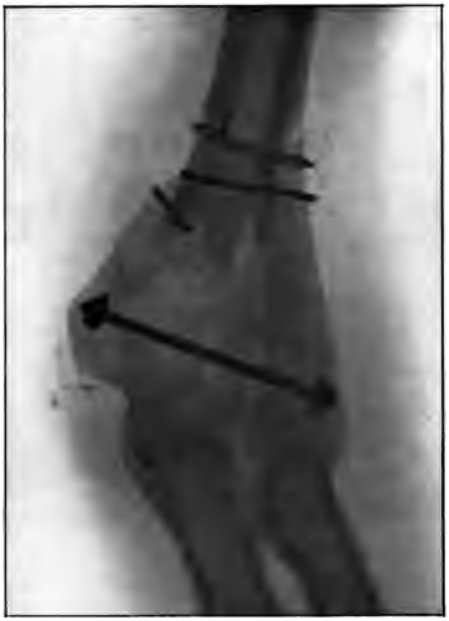

Fig. 113.—Complicated T-shaped fracture of the lower end of the humerus. The condyles are bolted together. The mass is fixed to the main shaft by wire.

broken ends are to be attached to the main shaft. Sometimes only one half of the articular end has been broken off, and in such a case the single bolt is all that is necessary. But if there has been a T-shaped fracture, the articular end must be reattached to the shaft (*Figs.* **113**, **114**). This may be done either by two nails (square, ivory) driven into holes bored through the epicondyles obliquely into the shaft, or by a pair of narrow flexible plates secured by metal-threaded screws to the lateral surfaces of the shaft (*Fig.* **115**). A second bolt transfixing the shaft will give greater security. Some difficulty may arise in accurately fitting the reconstituted articular end to the jagged extremity of the shaft. To overcome this the following plan is useful. After the bolt has been inserted through the articular end, and nuts have been screwed on to it over the terminal holes in two plates, about a quarter of an inch of each end of the bolt is allowed to project, and to these ends are screwed two handles

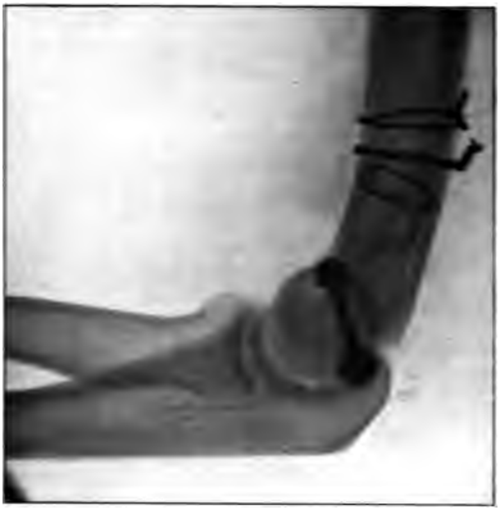

Fig. 114.— Same case as *Fig.* 113, seen from the side.

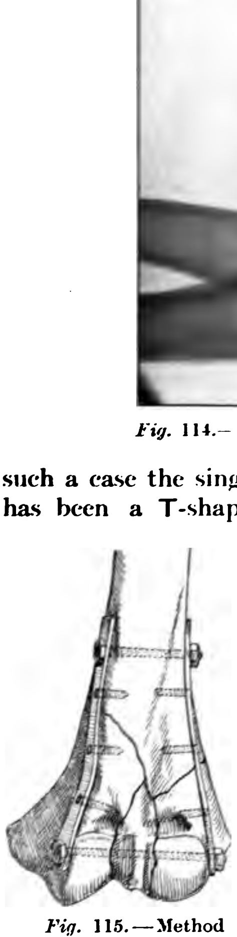

Fig. 115.—Method of bolting complicated fracture of the lower end of the humerus.

which enable a firm hold to be gained of the lower mass of bone, which can then by suitable manipulation be adjusted to the end of the shaft. The plates are bent into position and fixed by the screws or bolts before the handles are removed from the long bolt and the ends of the latter cut short. If the olecranon has been divided, it is re-united to the ulna in the manner described below, and the skin incisions are closed. Another method available, if the olecranon has been divided, is the use of a λ-shaped plate screwed on to the back of the humerus.

FRACTURES OF THE RADIUS AND ULNA.

Fractures of the Olecranon.—If the olecranon is fully separated by a fracture, there would seem to be little room for discussing the proper treatment. The majority of surgeons would not hesitate to do an open operation. But it has been demonstrated that many of these cases will do very well under the influence of 'massage' and mobilization, so that the necessity for operation is not so certain as might at first sight appear. The ideal treatment is a combination of operative fixation with 'massage,' and this will give a perfectly strong joint with rapid restoration of movement. Of the two elements in this treatment probably the early mobilization is more important than the operative fixation, and it is the greatest mistake in operation cases to leave the elbow bandaged for a fortnight in one position, when the mere fact of firm suture should make the employment of movements safe and easy. In the case of an elderly and nervous subject, where really efficient 'massage' is obtainable, it would be wiser to limit the treatment to this method, and there can be no doubt that not only is the process soothing and comforting, but the mental suggestion of the injury not being serious is a great help to recovery; whereas an operation has just the opposite effect, and the patient will be inclined to keep the part absolutely stiff in the latter case far longer than if gentle movement had been encouraged from the outset as the main element in the treatment.

In the case of a young adult, however, I think the proper course is to operate at once, and to follow and accompany this by 'massage' and movements from the very outset.

There are two methods of uniting a separated olecranon, nailing and wiring, and the latter is by far the best.

Nailing or Screwing has the advantage of requiring a very small incision, but against this must be set two serious disadvantages. First, the end of the shaft of the bone into which the nail or screw is driven is only loose, open, cancellous tissue which affords no efficient hold; and in the second place, the method does not allow of the removal of blood and soft tissues from between the broken surfaces. A square ivory nail is better than a screw, because of the soft texture of the bone. A vertical incision is made over the end of the olecranon, this is drilled through the fibres of the triceps tendon, and the nail is buried right up to its head.

Wiring the Olecranon is the routine operation. The bone may be exposed either by a vertical or a U-shaped incision, the former probably being the better. All the blood and tags of muscle or fibrous tissue are removed from the fractured area, and the bones are drilled transversely. One hole ought to lie just beneath the superior extremity of the olecranon, and the other in the shaft opposite to the first. A single loop of No. 20 or 18 (standard wire gauge) iron wire is threaded through both these holes, and then the separated fragment is accurately adjusted in its place and firmly held there whilst the wire is tightened and twisted. A few catgut stitches serve to bring together the soft parts over the sutured bone.

One further word may be added: In drilling the lateral aspects of the bone, no attempt should be made to bare it of the soft parts, the holes should be made right through muscle and aponeurosis, and when the wire is in place, little cuts are made in the soft parts into which the wire sinks when tightened. In this way the wire becomes buried in the structures round the bone.

Fractures of the Shafts.—It is very unusual for either of these bones singly to be fractured in the shaft with any marked displacement. And a great many of the fractures of both bones are merely subperiosteal, with fissuring and angulation, but no great dislocation of the broken ends. These fractures of one or both bones of the forearm with slight displacement are nevertheless very important in regard to their treatment, especially in the case of those whose occupation depends upon fine hand movements. They require no operation, but merely careful attention to function and position. In the slighter cases, 'massage' and mobilization, supplemented by an internal angular splint which is removed daily, are all that is required; but this must be done carefully by one perfectly conversant with light fracture massage.

Unfortunately this skilled and special 'massage' is often not available, and the arm is left in a sling and splint for a month, and will require perhaps two months after this to restore its full function. In all cases where skilled 'massage' is unavailable from the outset, and in those cases where both bones are broken, there are two principles of treatment which should always be attended to. These are extension and supination. Both can most readily be carried out by aid of the splints described and figured in Chapter III. Where there is no overlapping of the fragments the extension may be omitted, but the preservation of supination ought never to be neglected.

The trouble with forearm fractures through the shafts of the bones is always the limitation of the rotation of the radius round the ulna, and the bones tend to become fixed in a position of pronation. In most text-books it is customary to speak of the necessity for distinction in treatment between fractures of the radius above and below the insertion of the pronator radii teres. Those above this point, we are told, ought to be put up in full supination, and those below it, midway between pronation and supination. There is, however, much doubt about the wisdom of the latter advice. It is very common to see these cases later with the bones fixed in a position of almost full pronation, in which no supination can be carried out; whilst a fixed supination is the greatest rarity. The rule ought to be — let art secure supination, and nature may be trusted to secure pronation.

Supination can only be secured by a splint such as that referred to, or by a posterior angular splint. If the latter is used the wrist is encircled by a strip of strapping passing from ulna to radius across the front of the arm, the end being secured to the outside of the splint.

In Fractures with much Displacement, especially those of both bones, an attempt should first be made by extension to reduce the dislocation. This is done by traction under anæsthesia, followed by the use of the special splint. If after a few days the x rays show that the ends of the bones are still dislocated, then operation must be undertaken. But I believe that this will very rarely be called for if proper extension is used from the outset.

ANATOMICAL CONSIDERATIONS.—The forearm bones can easily be exposed by lateral incisions for almost the entire length of their shafts. Only the upper part of the radius, where it is wrapped round by the supinator brevis muscle and the posterior interosseous nerve, is difficult of exposure. The ulna is cut down upon along its subcutaneous border, in a line from the inner margin of the olecranon to the styloid process. The flexor muscles are retracted forwards and the extensor backwards, and the whole of the shaft of the bone is then exposed without interference with a single vessel or nerve of importance. Similarly, the radius may be exposed by an external incision in a line

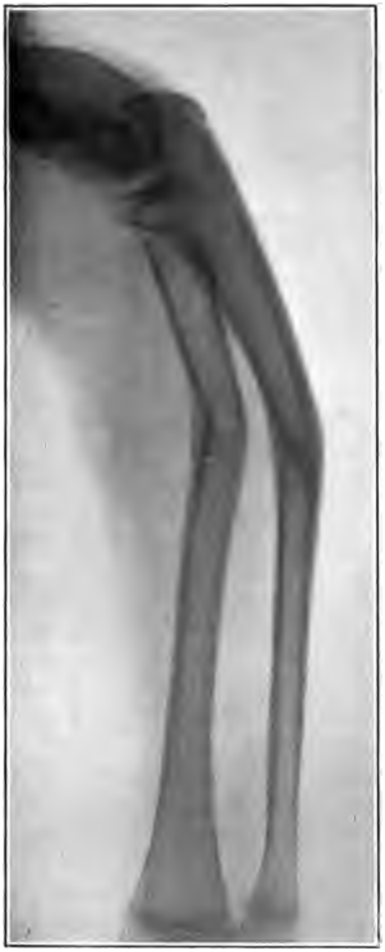

Fig. 116.—Mal-united fracture of forearm bones in a boy, before operation.

from the external epicondyle of the humerus to the radial styloid process, and then separating the supinator longus in front from the radial extensors behind. This latter act should be begun below where the tendons are quite distinct, and carried upwards to the level of the supinator brevis muscle.

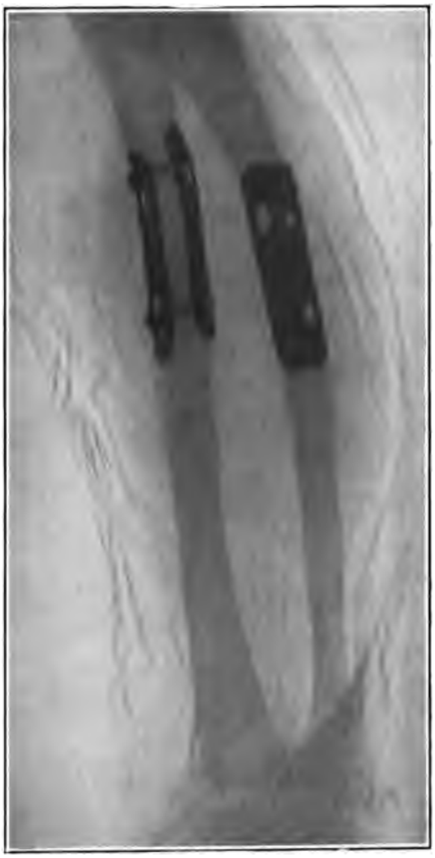

Fig. 117.—Same case as *Fig.* 116, after fixation with bolted plates.

Technical Considerations.—There are two methods of fixation especially suitable to these bones, viz., plates and intramedullary pegs.

Plates.—In using these, it must be remembered that there is no need to provide for any great strain, but of course the elements of mechanical efficiency must be observed here as elsewhere. The simplest form of plating which is mechanically efficient is that provided by a curved plate in which the screws are fixed. But as in these bones it is quite easy to expose the anterior and posterior as well as the lateral surfaces without damage to the soft parts, the application of transfixing-bolts is readily carried out (*Figs.* 116, 117). It is often unnecessary to use opposite plates, one being amply sufficient. For transfixion, either split pins or bolts and nuts can be used, the former being perhaps a little easier to apply, but the latter making a neater job when finished. The bolts are either $\frac{3}{32}$ in. or $\frac{1}{8}$ in. thick, and their heads and the nuts are countersunk in the plate and the bone (see also *Fig.* 109).

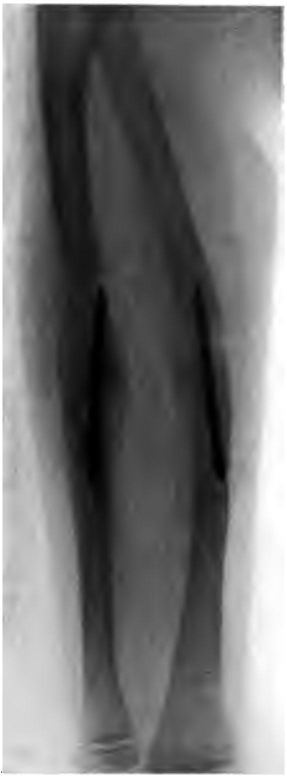

Fig. 118.—Fracture of both forearm bones: treatment by intramedullary pegs.

Intramedullary Pegs (*Fig.* 118).—It is in the forearm bones that the use of the short intramedullary pegs finds its best indication. It occasionally happens that a child gets a fracture of both bones with marked displacement of the ends which cannot be reduced by manipulation or extension. This is due to the fact that the soft parts have been torn, and lie between the jagged bones. In such cases an exposure of the bones, together with a restitution of the broken ends, would often be sufficient; but having cut down upon the bones, it is a pity not to do something to prevent the possibility of recurrent displacement. This can be done so easily by putting in short ivory pegs, that this method should be regarded as the best in these special cases. It is far easier of accomplishment than the fixing of plates, and it can be carried out through a much smaller incision.

The marrow cavity of the radius and ulna is about $\frac{1}{8}$ in. to

$\frac{5}{32}$ in. in diameter, and pegs and drills of these sizes should be provided. The technique is described in the preceding chapter.

FRACTURES AT THE WRIST.

There are few fractures so little suited to open operation as those of the lower end of the radius. The fractures without much displacement cannot be bettered by suture; if displacement is pronounced, it ought to be reduced, and then has but little tendency to recurrence. The fracture is rarely complete, and union is always rapid.

Undoubtedly, therefore, 'massage' and movement is the method of choice in the great majority both of Colles's and other fractures about the wrist-joint. Inasmuch as there exists no tendency to dislocation of the fragments after reduction, or to delay in union, no reason exists for bone suture. This is fortunate, because there is no bone in the body less suited to it than the lower end of the radius. Every part of its surface is surrounded by important tendons and ligaments, which are in many cases closely tied down to it. It is composed of a mass of spongy bone with only a thin shell of dense covering, so that metal screws take no firm hold in it.

There are two points, however, which require discussion in relation to operative procedures. These are reduction of gross deformity, and the treatment of old cases of stiff joint. Cases of impaction without much deformity ought not to be reduced; impaction is the first stage of healing. But when there is marked backward displacement with rotation, this will leave a very ugly hand, and will also limit the movements. But many cases of gross deformity with impaction are most difficult to reduce, even under an anæsthetic. The soft parts are already bruised and œdematous, and traction on the wrist and pressure on the dorsal aspect of the fragment, if excessive, will increase these injuries, often without altering the displacement of the fracture in the smallest degree. If, therefore, moderate force fails to reduce the fracture, as tested by the *x* rays, it is much better to resort to direct transfixion of the fragment than to use excessive force on the soft parts, or to leave the displacement unreduced. The fracture line is best exposed by a short incision on the posterior or outer aspect of the radius. A vertical incision about 1½ ins. long, on the outer side of the tubercle alongside which runs the long extensor tendon, is perhaps the best. Through the lower part of this incision the distal fragment is perforated by an ordinary metal drill with a stout handle, and by traction and gentle leverage on this the bone is manipulated into position until the posterior surfaces of the shaft and the fragment are in correct alinement. The drill is of course removed.

The Treatment of Old Cases of Mal-union.—In general terms these cases are quite unsuitable for operation. But there is one serious element of functional loss which can be remedied. That is the fixation of the lower radio-ulnar joint. Supination is lost, partly from contractions and adhesions in and around the joints, and partly from the altered mechanical relations of the lower ends of the radius and ulna.

This can be remedied to a large extent by the simple operation of the excision of the head of the ulna. Afterwards the hand is turned in as full supination as possible, and kept in this position on a posterior angular splint for some weeks, being taken down daily for massage and exercises.

FRACTURES OF THE UPPER END OF THE FEMUR.

These injuries are of the most diverse character, and their treatment requires corresponding variety. There are, however, two well-recognized types, viz., the comminuted fracture of the trochanteric region and the simple fracture of the neck, known by the old text-books as the extra- and intra-capsular fractures respectively.

Fracture through the Trochanters.—This fracture usually results from great direct violence. The neck of the bone seems to be driven down as a wedge, splitting off the great trochanter on the outer side and the lesser trochanter on the inner, the shaft being left as a fourth fragment. There is much tendency to deformity, which is of the nature of great shortening and a position of coxa vara. There is no tendency to delay in union. The comminution of this fracture makes it unsuited for operative treatment by any direct method, and indeed such is quite unnecessary if other modern principles be carried out properly. It is in such a fracture as this that the tying of the leg to a long Liston splint, and the attachment of a 10-lb. weight to the limb as extension, form such pitifully inadequate treatment, which is responsible for many a hopeless cripple to-day.

There are three principles of treatment for these cases, viz., extension, abduction, and early massage and movement.

The subject is generally a powerful working man, and perhaps there is some impaction. An anæsthetic must be given, the impaction broken down, and full extension with abduction carried out by means of a transfixing-rod driven through the lower end of the femur. The extension force should be as much as can be exerted by an able assistant pulling with all his weight, the patient being tied to the head of the operating table by a long towel round the perineal region.

The patient is put back to bed with the leg externally rotated and the knee bent over a pillow. A weight of 25 lb. is fixed to the transfixing-rod, and the perineal band is fastened to the opposite pillar at the head of the bed. The direction of the traction force must be one of marked abduction. A full dose of morphia is given directly pain begins, so as to keep the muscles in relaxation; but if full extension has been made under anæsthesia, weight traction causes much less pain than might be anticipated.

The whole limb lies uncovered by splints or bandages except just above the knee, and 'massage' is to be given from the very first day. The knee and ankle are moved from the third day, and the hip after a fortnight. The transfixion is removed after four weeks, but abduction and traction by strapping are kept up with a weight of 10 lb. for two weeks longer.

Simple Fractures of the Neck.—These are usually the senile cases, in which the fracture is caused by indirect violence, and in which there may be impaction.

Less common is the occurrence of a simple fracture of the femoral neck as the result of direct violence in a young adult. Such cases, however, are generally not simple, but comminuted.

However they arise, they present quite a different problem for treatment from that in the class just considered. Union of the fracture is slow and uncertain, and if it does occur naturally it will be in a position of coxa vara.

The extension and abduction treatment is not satisfactory, because it would have to be maintained for several months before the danger of deformity was over, and this prolonged recumbency is not well borne by elderly patients.

In many of the senile cases it is best to be content with 'massage' and light extension, followed by ambulatory treatment with the aid of crutches and a patten on the sound foot. It is hardly necessary to add that an impacted fracture should not be broken down.

When all the comminuted cases have been excluded on the one hand, and the impacted simple fractures with slight deformity or those in very feeble old people on the other, there still remains a third group, where the fracture is simple—i.e., the shaft and trochanters are solid—and where union is slow to occur, or occurs with varus deformity, in comparatively young or active persons. This is the only group in which operation is indicated, but there is as yet no consensus of opinion as to the method of such operation.

In nearly all cases, surgeons have been satisfied with driving or screwing metal pegs into the neck of the femur from the trochanter. I have examined a very large number of skiagrams of cases treated in this manner by various eminent surgeons, including those published in recent medical periodical literature. But none of these is at all convincing as to the efficiency of the method, either in bringing about union or preventing deformity.

This inefficiency is quite easy to understand when the structure of the bone is considered. The neck of the femur consists of a thin tube of dense bone, about 1½ inches in diameter, filled with delicate cancellous tissue, which, in most of the cases we are considering, is much softer than in the normal bone. What possible chance is there of a nail or screw holding in the midst of this loose, soft tissue? And when we consider that it is not merely the remaking of a bone at which we are aiming, but the forming of a strut which shall be strong enough to bear the body weight, it is quite evident that a nail in loose bone is inadequate. What is required is a massive peg capable of filling up the neck of the femur, supporting it at the correct angle with the shaft, and stimulating the formation of new bone for the natural process of repair.

Albee has demonstrated the principles on which these conditions may be fulfilled, by the use of a living peg taken from the patient's own tibia. He cuts the peg from the tibia, and then shapes it as an exact cylinder by what he terms a dowelling instrument, worked by a small motor.

I think that in several respects his technique may be improved upon. In the first place, the cutting of the peg into a circular shape by a rapidly revolving tool must tend to kill the superficial layers of bone cells, and to block up all the Haversian canals with bone dust, thus largely destroying its vital properties. Secondly, it is much better to use a rough square peg than a smooth round one, because the former will hold much better in the loose cancellous tissue of the neck of the femur. And lastly, Albee's operation, in common with all others which simply apply an external nail without exposure of the joint, is liable to fail in fixing the head of the bone to the shaft in a correct position.

OPERATION.—First, the peg is prepared from the anterior margin of the tibia. A slightly curved incision is made down the front of the shin with its convexity outwards, so that the main part of the incision does not lie over the bare bone. About 6 inches of the tibia is exposed, and the muscles and periosteum separated from it. The peg is cut by two incisions parallel to and half an inch from the crest and at right angles to the anterior and outer surfaces of the bone. These are conveniently made by the use of the circular saw which I have designed (*Fig.* 119). The length of the peg is 3½ inches. It is placed in warm saline solution until required. The soft parts are now brought together over the raw surface of the tibia.

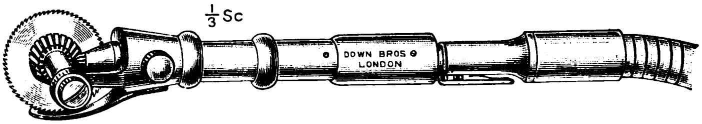

Fig. 119.—Author's circular saw, which cuts in the same plane as that of the cable which moves it.

Exposure of the Neck of the Femur.—A vertical incision 5 inches long is made from the anterior superior iliac spine downwards. This exposes the interval between the tensor fasciæ femoris on the outer and the sartorius and rectus femoris muscles on the inner side. These being retracted, the upper end of the femur is seen, covered by the vasti muscles. Along the intertrochanteric line run the outer branches of the external circumflex vessels. whilst above these is the capsule of the joint. The vessels are tied and cut, and the capsule opened and retracted. The head and neck of the bone are now seen, and by means of a hook or lever the proximal fragment is arranged in correct position.

Insertion of the Peg.—A vertical incision about 3 inches long is made on the outer aspect of the limb from the tip of the trochanter downwards, and deepened to the bone. On retracting the soft parts it is easy to identify a depression about an inch and a half below the tip of the trochanter and just below the insertion of the small gluteal tendons. The spot to be perforated may further be identified by feeling for the small trochanter, and taking a point on the outer aspect of the bone on a level with that projection.

The shaft is then pierced in an oblique direction by a Morse twist drill ⅜ in. in diameter. After the outer hard bone has been pierced, the remainder of the hole ought to be made with the shaft and neck very carefully held in proper position. To this end strong extension with abduction of the thigh must be carried out, whilst the neck of the bone is manipulated through the anterior incision. Then the drill can be inserted for 3 inches exactly in the axis of the neck of the bone. It will probably come as a surprise to most operators how very readily a large drill will perforate this spongy bone. The outer end of the hole should now be enlarged by a chisel so as to receive the head of the ½-in. square peg; but the hole must always be left smaller than the peg, so that the latter shall be driven tightly into it. The peg is then taken, and after being a little pointed by cutting off the corners of one end, it is driven into the bone for three to three and a half inches until it holds quite firmly.

The soft parts are sewn up and the limb is placed in a position of flexion and abduction with a moderate weight extension. The patient need only be kept in bed until the wounds have firmly healed, and then he should get up each day, using crutches and swinging the injured leg. Weight may be placed upon this six weeks after the operation.

Fractures of the Shaft.—In many respects this is the most important field for the operative treatment of fractures. In adults, it is very difficult, except by transfixion extension, to really reduce the deformity by non-operative means; extension treatment has to be kept up so long; it is impossible to avoid constantly disturbing any extension arrangement in attending to the patient's back and bowels; and inasmuch as the leg always has to act with its fellow, shortening and alteration of axis cause lameness. Another point not so generally recognized, but nevertheless true and important, is that when the fragments of the femur unite in an overlapping position, there may be only a trivial shortening at the time, but the uniting callus yields steadily before the pressure of the body weight and the tonic contraction of the thigh muscles, until the shortening at the end of a few months is very considerable (see *Figs.* 18–21).

For all these reasons, I believe that operation ought to be the routine treatment for the majority of complete fractures of the shaft of the femur in adults of active life. But if operation is to be done, it must be done with due regard to mechanical efficiency. The single plate with 'wood'-threaded screws is here most unsatisfactory, and it is the failure of this method which has in so many cases tended to bring the operative treatment of fractures into disrepute. The causes of failure of this common type of plating are all accentuated in dealing with the shaft of the femur. The outer part of the bone is so hard and dense that the 'wood' screws cannot bury their threads at all (see *Fig.* 103). Being a single bone, there is a tendency to rotation of the fragments upon one another, and this as well as the traction of the muscles quickly loosens the screws.

If any series of *x*-ray pictures of plated femurs be examined which have been taken one month after the operation, it will be seen that in the great majority the screws have become loose. If plating of this type ever succeeds, it is due largely to external splinting, and not to the plate and screws.

In my opinion, and for reasons which I have stated in the earlier chapters, there are only two methods of operation on the shaft of the femur which are satisfactory: first and best, the double bolted plates; secondly, the curved plates with converging screws threaded in the plates. The choice between these methods is determined by the fact that the curved plate is rather simpler and requires a shorter incision, whilst the bolted plate requires a little practice, several special instruments, and a long incision, but when done is absolutely efficient.

The Upper Third.—In this portion of the bone, the incision ought to be external, vertically downwards from the tip of the great trochanter. The fascia lata is divided by a I - shaped incision, the quadriceps muscle turned forward and the biceps backward, and the femur approached along the line of the external intermuscular septum. In this region it is impossible to expose the inner aspect of the bone, and the pair of plates must be put on the anterior and posterior surfaces. The muscles attached to the upper part of the linea aspera are in the way of the posterior plate. All these tendons, especially that of the glutus maximus, should be separated from the bone by a sharp chisel which lifts tendons and periosteum together, and this layer will serve well to cover in the plate at the conclusion of the operation.

The Middle Third.—In this situation the femur should be approached through an antero-external incision. This must be of ample length—8 to 10 inches in a muscular adult—and is in

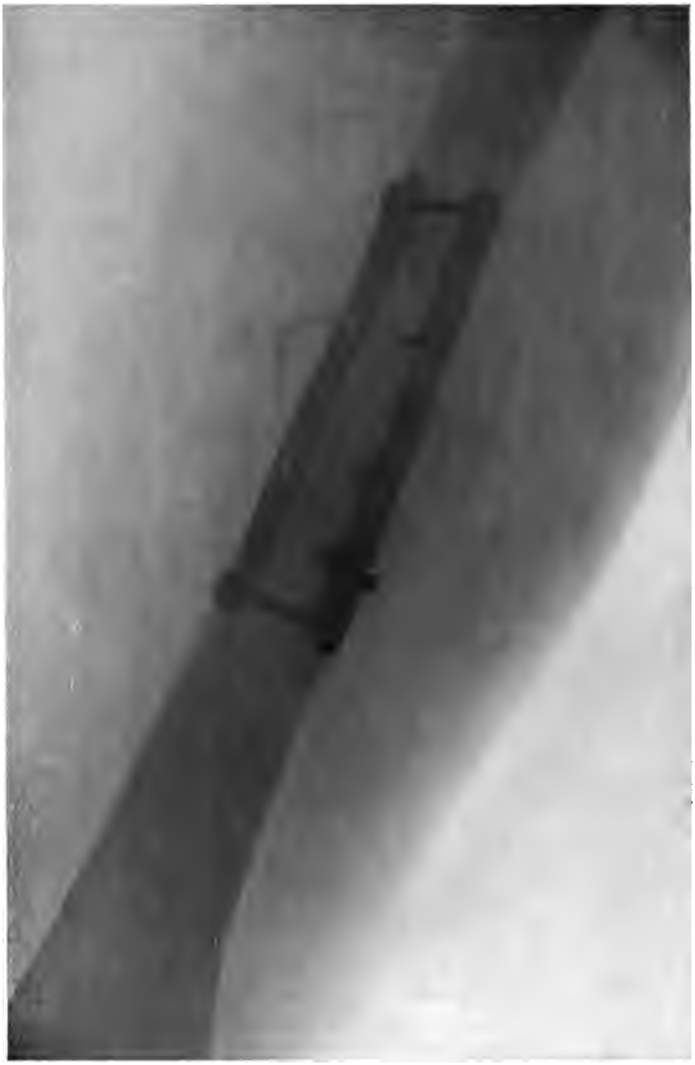

Fig. 120.—Fracture of the middle of the shaft of the femur, treated by a pair of bolted plates. The patient, who was a motor cyclist, won a championship race six months after the operation.

a line between the inner part of the anterior superior iliac spine and the outer border of the patella. The rectus femoris is retracted inwards, and the quadriceps divided longitudinally along the inner border of the vastus externus. The latter incision must not go so high as to divide the nerve to the latter muscle. This nerve, with a large descending branch of the external circumflex artery, crosses the femur at the upper third of the bone.

Fractures at the junction of the upper and middle thirds are therefore best exposed by the external incision described in the last section. In the middle of the shaft, the bone is easily exposed along its anterior, outer, and inner surfaces by turning aside the two halves into which the quadriceps has been split. The plates are applied to the inner and outer surfaces, and when in place they are snugly covered in by the replaced crureus muscle (*Fig.* 120).

The Lower Third.—In the lower third of the femur, it is much more convenient to employ two opposite incisions than to attempt to work through a single one. Each incision is on the lateral aspect of the thigh, vertically upwards from the most prominent part of the condyle. The vasti muscles are divided in the length of their fibres. In this part of the bone, and with these incisions, which need only be a little longer than the plates which are to be used, it is not practicable to employ the special extension clamps described under the general technique. But the double transfixion apparatus will be of great service in preliminary extension.

FRACTURES INTO THE KNEE-JOINT.

These fractures, when complete, ought always to be treated by open operation, in order accurately to restore the knee-joint. The technique of the operation is similar to that employed for the lower third of the femur, except that the lateral incisions are somewhat lower down and should penetrate the knee-joint, cutting through the lateral ligaments of the patella. The importance of freely opening the knee-joint consists in the fact that without this it is impossible to be quite certain that the articular surfaces are accurately re-adjusted to make a perfect joint for the knee. If only one condyle or tibial tuberosity be separated, and the other remains in continuity with the shaft, the operation is very simple, consisting merely in a transfixion of the bone and the application of a single bolt (*Fig.* 121). In a T-shaped fracture, where both condyles or tuberosities are separated from one another and from the shaft of the femur or tibia, the operation is on the same lines as that described for the lower third of the femoral shaft. In the case of the femur, the condyles are adjusted accurately, and bolted together through the lowest holes of two thin flat plates (3 in. by $\frac{1}{2}$ in. by $\frac{1}{16}$ in.) (*Fig.* 122). Then the condyles are placed in proper relation to the shaft, using traction by suitable handles on the bolt already in place. The plates are then bent into position by means of the screw clamp drill-guide, until they lie snugly against the lateral aspects of the lower end of the bone. The upper bolts are applied in the holes made through the screws of the drill-guide. An exactly similar operation is suited for the upper end of the tibia.

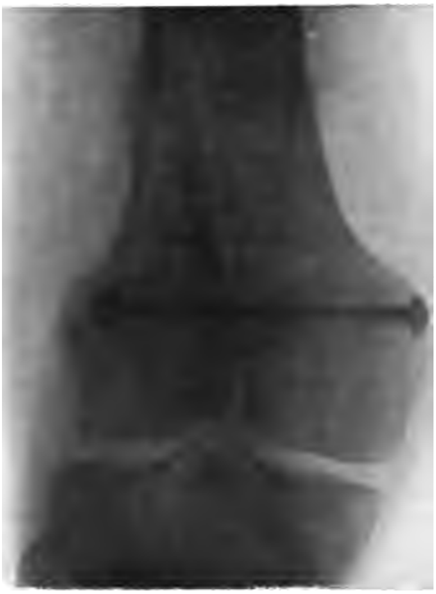

Fig. 121.—Bolting of the external femoral condyle.

Fractures of the Patella.—It was in the case of complete transverse fractures of this bone operative measures were first suggested, and it is here everyone agrees that operation is the method of choice. And yet there are many points which require emphasis in order that the operation may be of speedy and lasting benefit.

If a transverse fracture of the patella is not operated upon, the fragments become pulled apart, the torn aponeurosis falls down over the broken surfaces, and little or no callus results. In course of time the fibrous union stretches, the knee remains weak, and the rigidity of the leg is much impaired.

And yet there is abundant evidence that the operations commonly done for this fracture are by no means uniformly successful. Many cases have occurred of so-called re-fracture of the patella, and others of non-union, or rather of stretched fibrous union, after suture. I am convinced that the causes of these failures lie in the choice of wrong materials and in the faulty application of the sutures.

Suture Material.—The common material used for the patella is silver wire, but as I have already pointed out, this is weak to begin with, and it soon becomes weaker by sulphide formation. But it is especially when silver wire is placed in the form of vertical loops with sharp kinks, that it is utterly unreliable, and this I shall speak of below.

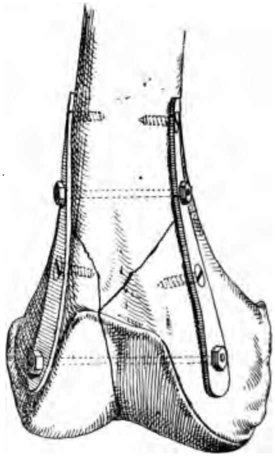

Fig. 122.—Bolted plates applied to a T-shaped fracture of the lower end of the femur.

Lately it has become the fashion to attribute the bad results in bone suture to the presence of unabsorbable foreign bodies in the tissues, and to assume without any basis of proof that the wire prevents proper bone union. This is quite incorrect. It is not the presence of the wire, but its application in a wrong manner and the use of weak silver wire sharply kinked, which is responsible for the failure. Those who blame the unabsorbable suture now use stout catgut, with which they sew together the aponeurosis in front of the patella and at its sides. But this is a very unreliable method, and depends upon the leg being kept in rigid extension for a long time, lest the fragments be pulled apart by muscular tension before bone union has occurred. To use catgut for the suture of bone where callus formation is slow and slight is merely asking for failure, and to use a method which requires six or eight weeks' stiffness of the knee is not only tedious, but likely to give very slow recovery of movement.

The best suture material is soft iron wire, which may be nickel-plated, but this is not essential. For the patella is required a gauge of 16 or 18 (standard wire gauge).

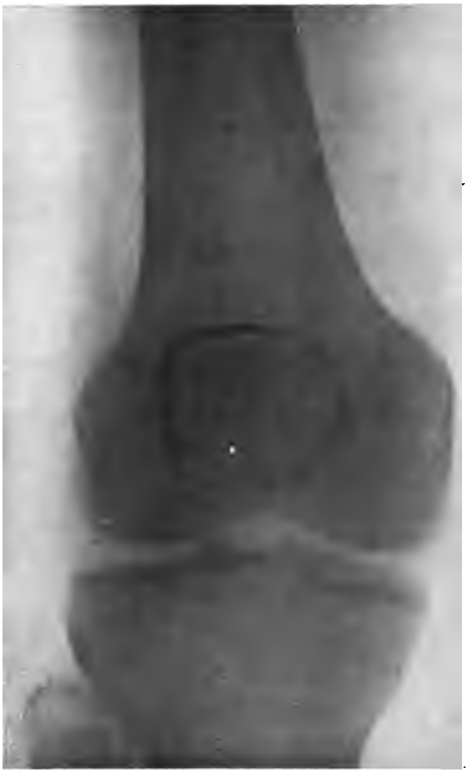

Fig. 123.—Double wire encirclement of patella. Patient was able to walk fourteen days later.

The Method of Suture Application.—It is common in text-books to find descriptions and figures representing the wire sutures being placed vertically. This is bad, because the loops must be sharply kinked, and when they are tightened this tends to tilt the fragments, separating the articular surfaces. The best way is to apply the wire suture as a horizontal loop or circle surrounding the circumference of the patella and merely perforating a small groove in the upper and lower margins of the bone. A double loop of wire gives a much more symmetrical traction upon the bone than a single one. The extreme upper and lower margins of the two fragments are perforated transversely by two holes, one towards the front surface, the other towards the back. Two long loops of wire are taken and the ends threaded into these holes, the one from the outer side and the other from the inner. This gives two free ends of wire projecting from each side. Each of these is attached to a handle (a pair of pressure forceps answers the purpose well), and the surgeon and his assistant then each grasp one pair of wire ends, and having crossed them, make strong, steady traction. This brings the fragments together with great precision. Before finally twisting and cutting off the ends, the wire should be allowed to sink down to the sides of the bone, by cutting into the soft tissues which underlie it. Then the last tension is given to both wires at the same time, and they are twisted and cut off. They lie buried in the soft tissues (*Fig.* 123).

The aponeurosis in front and at the sides of the patella is closely sewn together by catgut stitches. No splint is required. 'Massage' is instituted within the next few days, and after the skin is healed the patient may bend the knee and walk. A patella treated in this way is stronger than before the fracture, and I have never known either re-fracture or separation of the fragments.

Cases with much Separation of the Fragments.—It sometimes happens that cases come for operation long after the accident, when considerable separation has taken place, amounting to two or more inches. The fundamental act in such a case consists in an adequate freeing of the upper fragment in order to bring it down to the lower. To separate the tubercle of the tibia, and so mobilize the lower fragment, merely substitutes one fracture for another, and to unite the separated fragments by kangaroo tendon or catgut only makes another form of fibrous union.

The incision in this and all cases of operations on the patella should in the first place be ∩-shaped with the convexity upwards. This places the subsequent skin scar away from the kneeling surface of the limb. If more room is required to free the upper fragment, the ∩ is converted into H by prolonging the lateral limbs of the ∩ upwards. The ∩ should be made the full width of the knee, with a view to avoiding a narrow ill-nourished flap. After the skin flap has been turned down, the joint is fully opened between the fragments of the patella; the fibrous band between the latter should be carefully preserved attached to one or other piece, as it makes a most useful flap for the final suture. It will now be found that the upper fragment is closely tied down to the lower end of the femur, partly by adhesions and partly by cicatricial contraction of the torn capsule and quadriceps. It must be separated from the femur quite freely, by cutting through all the soft tissues on both sides. When it has been reflected upwards to the level of the suprapatellar pouch, the edge of the latter is cut from the patella and if possible brought down and sewn to the anterior margin of the lower end of the femur, thereby preserving the synovial pouch which separates the quadriceps tendon from the bone.

If there still remains any difficulty in bringing down the upper fragment of the patella, this must be overcome by dissecting upwards with anatomical accuracy the quadriceps muscle from the front of the lower third of the femur until the entire structure with the upper fragment can be easily pulled down into position. This involves separating the vastus internus on the inner side from the adductor magnus tendon, the vastus externus on the outer side from the biceps, and the fibres of the subcrureus and crureus muscle from the femur. But practically all the difficulty lies just above the patella, where a mass of scar tissue has tied the quadriceps down, giving it a new attachment to the femur. When this has been freely divided the rest of the muscle strips up quite easily. Then the patella is held and sutured exactly as described above, and the flap of fibrous tissue which was preserved from the fibrous union is brought up over the line of fracture and fixed by a few sutures.

FRACTURES OF THE TIBIA AND FIBULA.

Fractures of the Shaft of the Tibia.—Here, as in the shaft of the femur, severe displacement will inevitably lead to permanent loss of function, and the bad types of displacement are exceedingly difficult to reduce by non-operative methods. But the causes of the difficulty of reduction and the poorness of the functional results are different here from those obtaining in the thigh.

An oblique or spiral fracture of the tibia is difficult to reduce because the sharp points of the broken bone become entangled in the dense fibrous structures, particularly the intermuscular septa and interosseous membrane. It is certain to give a bad functional result when not reduced, because both rotation and lateral deviation throw the ankle-joint out of line, and produce such deformities as flat-foot and talipes valgus. (See *Fig.* 7.)

It was in connection with the fractures of this bone that most of the pioneer work on operative treatment was done, because of the obviously bad results given by cases imperfectly reduced and treated by mere splintage.

The selection of the method of treatment is to be exactly on the lines already laid down—i.e., every case is to be operated upon in which *x* rays show that severe dislocation exists in spite of manipulation or extension.

ANATOMICAL CONSIDERATIONS.—The tibia in many respects is the easiest bone for operative work. The shaft is roughly triangular in section, and nearly the whole of the antero-internal surface is subcutaneous.

The muscles on the front and outer side of the bone can be separated from it with great facility, and then we have the whole shaft standing out beyond the level of the soft parts in a way which occurs with no other bone.

The superficial character of the antero-internal aspect demands, however, certain special cautions. If possible, this surface should not be used for the application of plates, which would come to lie just under the skin. Further, it is wise to avoid any skin incisions over the anterior border or over the subcutaneous surface in the neighbourhood of the fracture. This is effected by making a single curved longitudinal incision with its convexity outwards—or better still, by a double incision.

OPERATION.—In most cases this ought certainly to be by the bolted plate method. In a few, however, the curved plate with radial screws will be useful. These few cases are those of open fracture in which immediate operation is done for the purpose of cleansing the wound. In such cases it is a pity not to fix the bone, and yet it is unwise to open up the part by other incisions, and in such circumstances the special plate is just suitable. It can be placed on the postero-internal border or on the external surface, and in both these positions it is well covered by soft parts.

In the application of the bolted plate, little need be added to the general account already given of this method. The use of the powerful double transfixion apparatus is very important, because it enables the deformity to be exactly reduced, the long transfixing-rods making accurate rotation easy without disturbing the extension.

If the leg is very muscular, it is best to make two incisions: the first is over the anterior muscles, just in front of the fibula. The muscles are easily separated from the bones, and the plate is fixed on the flat external surface of the tibia. The bolt-holes are perforated and the bolts put in such a position that their ends push out the skin on the internal aspect. Then an internal curved incision is made behind the ends of the bolts, and the parts are turned forwards until the bolts are exposed. The holes in the bone are deeply countersunk, the conical nuts screwed into place, and the ends of the bolts cut off. Thus the bolts and nuts on the inner surface come to lie deep to the surface of the bone, when they soon become buried in periosteal callus. The plate itself, covered by muscle, will remain permanently in place.

I have often used double bolted plates applied to the tibia through a single curved incision (see *Fig.* 110); but I think that the technique just described is better, inasmuch as it involves less dragging of the muscles in order to expose the external aspect of the bone.

Fractures of the Shaft of the Fibula.—These have very little importance from an operative point of view. If the tibia is well and soundly fixed, the fibula can usually be left to take care of itself, and in fractures of the fibula alone there is seldom any marked displacement of the fragments, such fractures requiring nothing but 'massage' and mobilization. It may occasionally happen in fractures of the tibia and fibula that there is much displacement of the fibular fragments which it is worth while to rectify by suture. It is important, where this is the case, to do it after the tibial operation, because the manipulation of the tibia is much easier when the fibula is freely separated into two fragments.

I do not think any elaborate operation is ever required. A small peg is perhaps the most efficient method, but a plate or wire will quite serve the purpose.

FRACTURES IN THE NEIGHBOURHOOD OF THE ANKLE.

It is neither possible nor desirable to go into details about all the many varieties of fractures about the ankle-joint. For the present purpose it will be sufficient to divide them into those with no displacement—which need not be further discussed here—and those with much displacement which will probably require operation. The second group may be subdivided into supramalleolar, malleolar, fractures of the astragalus, and of the os calcis. In the following sections it must be understood that I am only referring to cases in each group where there is marked displacement which has not yielded to correction under an anæsthetic.

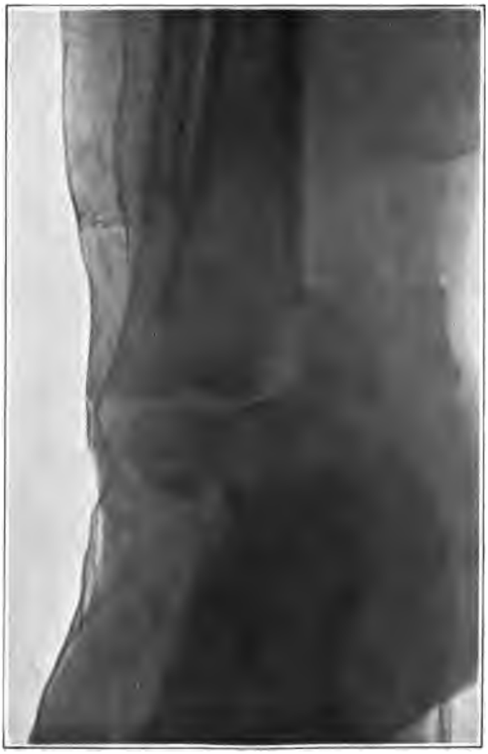

Fig. 124.—Malleolar fracture with marked displacement.

Supramalleolar Fractures.—These fractures not only disorganize the ankle-joint, but they are liable to produce adhesions of the tendons running in front of the bones. The lower ends of the tibia and fibula are spongy bones which will not hold screws. Accurate reduction is often very difficult.

Operation.—Double lateral incisions are required, but should be curved, with convexity forwards, so that the sutured wounds will not lie over the line of the plates. The lower ends of the tibia and fibula are first adjusted accurately to one another in those cases where they have been torn apart. Then the bones are transfixed. It is safe to take a point 1 inch above the tip of the internal malleolus and towards the back of the inner surface of the tibia. This will avoid any danger of entering the ankle-joint. A corresponding point is taken on the outer side of the fibula. Each of these points is marked with a broad drill, the bones are clamped together with the clamp drill-guide, and the bones pierced. A long bolt is used through the proper hole of a pair of plates, and nuts are screwed on, leaving the ends for the attachment of traction handles. By these the distal fragments are pulled down into proper position, the plates are then

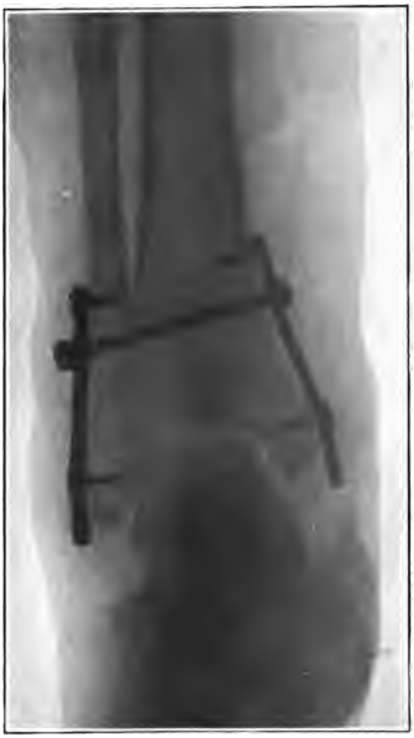

Fig. 125.—The same as *Fig.* 124, after the application of bolted plates. The patient was a woman weighing 18 stone, and she had good ankle movement six months later, being able to stand on tip-toe.

bent into shape, and fixed by the screws which are threaded in the plate. In this fixation the bolt holds the plates and fixes the lower fragments together, whilst the short screws serve to keep the distal fragments in proper position in relation to the shafts (*Figs.* 124, 125).

There are certain cases of comminuted fracture of the lower ends of the tibia and fibula in which not only are the bone fragments in great disorder, but there is much swelling of the soft parts, with formation of blebs and an unhealthy condition of the skin. In such cases, especially in elderly subjects, it is far better to attempt no direct operation on the seat of fracture, because it is impossible to restore all the pieces of bone to their proper position and keep them there; and further, the circulation being poor and the skin not sound, suppuration will probably

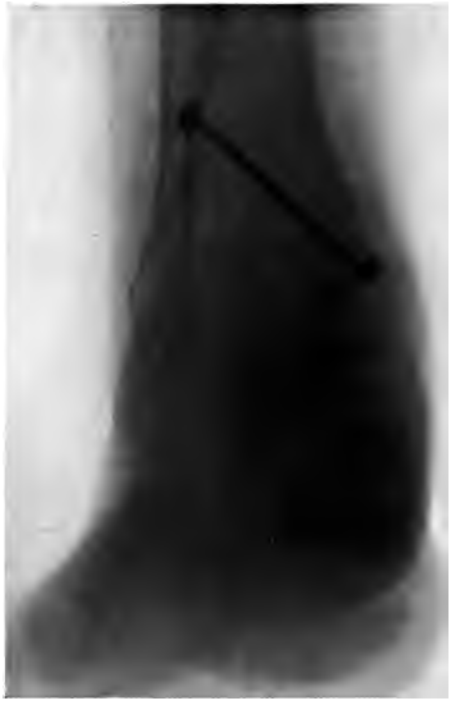

Fig. 126.—Fracture of the internal malleolus and astragalus in a man aged 20. The internal malleolus is bolted in position.

occur secondarily, and this will lead to disaster. I would repeat that these supramalleolar fractures require for good operative results a fairly simple type of break, absolutely healthy skin, and a youthful patient. In other cases it is far better to apply the indirect method of double transfixion, the lower rod passing through the os calcis. (See *Figs.* 38, 39, 40.)

Malleolar Fractures.—In these injuries, which complicate certain cases of dislocation of the ankle-joint, one or both malleoli may be broken off. If the foot can be replaced and the skiagram shows that there is good position of the bones, then the only treatment required will be 'massage' with movements, using a splint for about a fortnight. But in many cases a correct position cannot be obtained, or displacement recurs. In such cases the separated malleolus is apt to join the bone in a position which permanently deforms the socket for the astragalus, and a lasting deformity of the nature of flat-foot or talipes valgus results (see *Fig.* 8).

Fig. 127.—The same case as in last figure. The fragments of the astragalus have been removed. The man was able to return to work in four months time.

In these cases, the most secure operative fixation is obtained by the use of a single bolt passing obliquely upwards through the lower ends of tibia and fibula, with a nut at the opposite side (*Figs.* 126, 127.)

Murphy has introduced the method of percutaneous nailing, and he uses heavy round metal nails which can easily be removed. This method has the advantage of avoiding any incision except a mere puncture of the skin. It may be improved upon, I think, by substituting square ivory nails, which hold better than the round metal ones, and which become incorporated in the bone in time.

Fractures of the Astragalus.—The only varieties of this injury which require operative treatment are those where the bone is comminuted and the fragments displaced or dislocated. In such, the only prudent course is to remove the whole bone, and the results of this procedure are so good, that I think no other operation should be attempted. It would be very difficult to properly replace the fragments in relation to each other and to the ankle-joint, and their union would be accompanied by so much callus formation as to limit the movements of the joint. (See *Fig.* 127.)

Fractures of the Os Calcis.—There is only one type of fracture of this bone which may require operation, namely the transverse separation of the posterior process. This has usually been treated by the use of a nail or screw. But for exactly the same reasons which were urged in the case of the neck of the femur, this is not satisfactory. The os calcis is a mass of spongy bone in a very thin shell. A screw takes no hold upon this tissue. Moreover, the bone will have to resist the pressure of the whole body weight and the pull of the tendo Achillis. Therefore a stout square ivory nail should be used, or better still, a ¼-in. peg cut from the front of the patient's own tibia.

CHAPTER VIII

OPEN FRACTURES

IT is beyond the scope of the present work to do more than indicate the modifications in the treatment of open fractures which ought to be imposed by modern methods, and more especially by direct operations.

There was formerly a tendency to limit operative treatment of fractures to cases of open bone injuries. The bone being exposed, it seemed to involve no risk to suture it, and hence various attempts at 'wiring' fractures were in vogue long before the modern era. The results were far from satisfactory, chiefly because the fragments were but inefficiently tied together by wire, which allowed both movement and deformity.

After operation was proposed and practised for closed fractures, the principle that asepsis was necessary for success in bone suture so dominated our conception, that all open fractures were regarded as outside the scope of the new method, and now this tendency has perhaps gone so far as to encourage too much of a *laissez-faire* policy in the treatment of these injuries. The fact seems to be that here, as elsewhere in surgical practice, there is no one method which ought to be adopted for a whole class of cases ; but that the first essentials of proper treatment consist in the differentiation of different groups, and the selection of treatment appropriate for each.

It will be convenient therefore to classify open fractures under the following groups : (1) *Cases where the wound is trivial and clean ;* (2) *Cases with an extensive, but clean, wound* ; (3) *Cases with a definitely septic wound which is not in itself dangerous ;* (4) *Cases of severe sepsis of a dangerous character.*

GROUP 1. *The wound is trivial and clean.*—Many of these are cases of primarily closed fractures by indirect violence where a spicule of bone has pierced the skin from the deep surface, and the absence of local inflammation or rise of temperature within the first few days of the accident shows that there has been no infection.

Such cases are to be treated by extension, the wound being cleaned but not probed, painted with iodine, and covered by a dry dressing. At the end of a week, if the *x* rays demonstrate that the position of the fragments is bad, operative treatment can be undertaken exactly as in the case of a closed fracture. It is better to avoid making the operation incision in the line of the original skin wound, and this can always be done by a suitably curved line.

It is, I think, far better to wait even for three weeks for the skin to be soundly healed and dry, than to act before this has occurred and risk operative failure. If the skin wound is very slow to heal, this indicates that the conditions are not favourable for operation.

GROUP 2. *Cases with an extensive, but clean, wound.*—In these cases the wound is large, so that the area of fracture is widely exposed by it.

If the case is not seen until more than twenty-four hours after the accident, it must be treated on the same lines as the first group, that is to say, a suitable and efficient extension apparatus must be applied ; but there must be no attempt made to operate at the seat of fracture. However clean the wound looks, it is potentially septic, and any opening up of the tissues with plating will probably lead to failure, and may endanger the vitality of the whole limb.

In this group of fractures, the transfixion or the double transfixion apparatus which is described in Chapter IV is particularly indicated. It is unlikely that the wound will heal soundly enough to justify a direct operation before bone union has taken place, and weight extension is not only tedious but difficult to apply efficiently in the presence of a large wound. On the other hand, the double transfixion apparatus leaves the whole limb free at the site of injury, and the transfixion is at a distance from the wound, so that it can be performed without fear of infection.

Further, the presence of the open wound exposing the fracture will allow of an accurate adjustment of the broken bones before the apparatus is finally tightened and fixed. In this way a very perfect result may be obtained, because the bone is placed and kept in good position, the wound can be dressed as often as necessary, and the joints, being left quite free, can be moved at an early date.

If the case is seen at once, or within a few hours after the injury, and if the wound is clean, it is then justifiable to carry out a modified form of bone suture.

This must be such as will not involve the making of any further incisions or opening up the tissues to any great extent. The plate with radial screws is the most suitable appliance for this purpose, and after its adjustment the wound is closed in just the same way as after a primary operation for a closed fracture. In some cases one or two ivory nails, or two well-adjusted wire circles, may better meet the indications.

This plan of primary operation for some cases of open fracture is mentioned because it has often given good results; but it is probable that it has often been followed by failure, because the conditions are not those of asepsis.

Transfixion, on the other hand, involves no risk of making matters worse, and if properly used it should be regarded as the safest and most accurate method for the majority of cases of open fractures.

GROUP 3. *Cases with a definitely septic wound which is not in itself dangerous.*—Cases of compound fracture by direct violence, where the skin has been torn and dirt ingrained into the tissues, form the majority of this group. In a general way the treatment should be on the same lines as in the last group, that is, by extension. And, further, the double transfixion apparatus forms the ideal method by which efficient extension is to be applied without interfering with the dressing of the wound. But the presence of a focus of septic infection at the site of fracture is an important circumstance in which this group differs from the last. If the limb be immediately transfixed and put up in extension, without waiting for the wound to throw off the infection, there is a very real risk of the transfixion holes also becoming septic. It is easy to understand why this is so, because there is a free communication by means of the lymph vessels between the wound on the one hand and the punctures on the other.

I am quite convinced, therefore, that where there is active sepsis in the fracture wound, nothing ought to be done at first beyond immobilization. This does not mean waiting till the wound has healed, or even become aseptic in a bacteriological sense. It means merely waiting until the wound has become healthy in appearance; the sloughs removed, dirt, foreign bodies, and bits of dead bone thrown off, and the whole wound surface lined by healthy granulation tissue. To promote this condition, the wound should be enlarged, if necessary, so as to promote free drainage; and a degree of passive congestion by a rubber bandage, applied for about twelve hours at a time to the proximal part of the limb, will hasten the tissue reaction. In most cases the wound thus treated will rapidly respond, and within ten days will have become clean and set up a barrier of granulation tissue which prevents extension of the sepsis to other parts of the limb.

But however long the wound takes to become healthy, it is time well spent, and it is quite useless to attempt bone repair until this phase is over. No bone growth or bone healing begins until the appearance of granulation tissue. In fact, the early callus of an open fracture is granulation tissue. Therefore the appearance of this tissue should be the signal that the time has come to look after the restoration of the bone. Then, and not till then, should the transfixion be applied.

GROUP 4. *Cases of severe sepsis of a dangerous character.*— In these cases, amongst which are many conditions of crushed limbs or of gunshot wounds, the severity of the sepsis dominates and overshadows all other considerations. It is the same problem as in the last group in a more accentuated form. Here it is not at first a question of what sort of bone we are going to preserve; but whether we can preserve life and limb.

There are several septic bone ends lying more or less deeply in torn muscles and fascia. If such a limb be treated by a straight splint with bandages or any form of extension, there will be a tendency for all the soft tissues to be closed over the bone.

The limb requires to be supported by some sort of trough splint, and fixed to this by its extremities, leaving the wounded area freely accessible and only loosely bandaged. Only sufficient extension should be made as may be necessary to immobilize the limb, In many cases it is far better to rather increase the overlapping of the bone ends, or to angulate them, so that the septic bone area be made to assume as superficial a position as possible, and the soft parts fall aside in a way which permits a free access to the depths of the wound.

At this stage, freedom of the circulation and ready access to the wound are the main desiderata. For example, in a septic open fracture of the leg bones, the limb is arranged between sandbags, and is flexed at the point of fracture, so that the bones are sticking out of the wound. An elastic bandage should be applied above the knee for about sixteen hours a day in order to promote passive congestion.

When the acute sepsis has subsided and the wound begins to granulate, any points of bone which are obviously dead should be removed, and then when all is clean, the limb is straightened and treated by extension.

This method will prove effective in saving limbs which otherwise might require amputation. If there is loss of bone by necrosis, this is reduced to a minimum, instead of proceeding to a maximum.

ON THE TREATMENT OF SEVERE GUNSHOT FRACTURES.

The present war has made this question one of the most pressing importance, and although the general principles just enunciated hold good, yet it is necessary to add various details brought into prominence by the exigencies of the time.

Surgeons for the most part have been so absorbed in abdominal or cranial surgery that they have not given much special attention to the problems of fractures. A severe open fracture has been a comparative rarity in civil practice, and even when such has occurred, it has first presented itself in the wards of a hospital, so that questions of transport or of treatment during transport have not arisen.

But now, at all the great base hospitals the biggest problem of surgical treatment is that of the shattered limbs, which actually form about 60 per cent of all the serious cases.

First Treatment of the Wound.—The sepsis which attends these injuries is far the worst feature, and one which we had hardly expected, since we had fondly imagined that sepsis in surgery had been conquered. The extent of this sepsis is due to the two factors of gross contamination by foreign bodies, and the long delay in serious dressing, and it can hardly be prevented: or rather its prevention concerns the military medical administration, and is not a question of surgical principles. If the case is seen, and if necessary anæsthetized, within twelve hours of the infliction of the wound, then cleansing is a matter of careful detail in opening up the ragged wound, removing dirt, and washing out with antiseptics. But as a matter of fact this early thorough treatment is seldom possible, and the case when it first arrives in hospital is foully septic and the patient in terrible pain.

Transport to the Base Hospitals.—When the legs are severely wounded, the carrying of the patient on a narrow flat stretcher is productive of much pain, and may cause further injury. This is because when a patient is laid flat the body tends to roll, and there is nothing to keep the broken leg rigid. It is quite easy to overcome this by the use of a special stretcher which supports the patient in the semi-reclining position with the knees bent up and all the leg joints semiflexed. Apart from the advantage of this position for cranial, chest, and abdominal cases, with which we are not here concerned, this type of stretcher will serve to keep a shattered leg much more comfortable than one which is quite straight. The patient's position prevents him from rolling, however much he is jolted. And both the thigh and leg bones are held suspended from the knee in such a way as secures the bones being held straight and gently extended so that the fractured ends do not rub against one another. Moreover the side bars of the stretcher form splints to which the leg may be bandaged for further security. The stretcher will stand on the floor of a motor or railway train, or can be slung in either. In this way the wounded man can be carried from the field to the base hospital with the least possible pain or injury.

Long-Journey Transport.—Theoretically, I can see no reason to move the patient from this stretcher until he has reached the destination where he is to undergo the chief treatment of his injury. He could well be taken on board ship, and again in a train, without being disturbed. The junction between the body and thigh supports is formed by two broad canvas bands, with an interval of six inches between. This allows of the bed-pan being used without lifting the patient at all.

But there are practical difficulties of an administrative nature which make this scheme impossible of application on anything like a large scale, and it will therefore be necessary to discuss other means of transport suitable for fractured legs at an early stage after the receipt of the wound.

The only appliance which appears to me to be both simple and efficient for this purpose is a wire cradle splint shaped in the form of a double inclined plane. This is shown in *Fig.* 128, though the latest pattern is lighter and more portable, and also cleaner, having an open metal framework for a base instead of the wooden board. The knee, semiflexed, is supported eleven inches above the bed. The leg below the knee, sloping downwards towards the foot, holds up the thigh, the action of the splint being similar to that of an attendant who holds up the leg of a patient with a fractured femur, taking the limb by the knee and ankle; but here, in addition, the thigh itself is supported by slings. The wire cradle is fixed on a board thirty-four inches long, which gives it a firm support. The cradle is prepared for use by slinging strips of flannel or rubber bandage across from side to side, the latter being placed where the wound will come. Then the wounded limb is simply flexed at the thigh and knee and placed in the cradle so prepared for it, when by a proper adjustment of the tension of the various slings, sufficient extension can be obtained to keep the thigh in good temporary position. With the knee semiflexed no rolling is possible, and the wounds can be dressed without moving the leg from the splint.

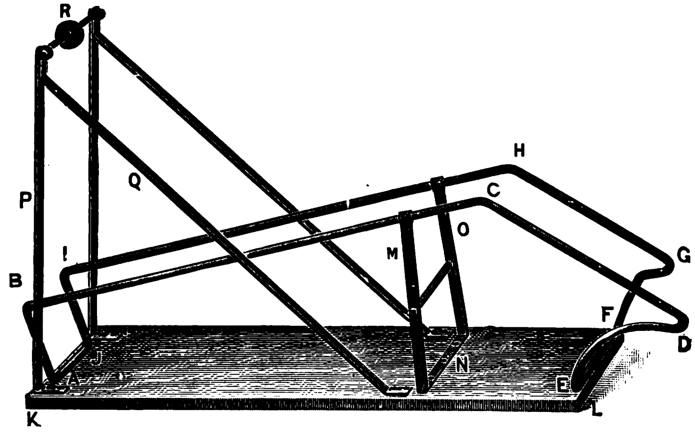

Fig. 128.—Wire cradle leg splint, for transport or extension. The splint is constructed of mild steel wire, $\frac{1}{4}$ in. thick, fixed on a board as shown. The two flat steel uprights bearing the pulley wheel can be screwed to the board if required, so that extension can be used without moving the limb from the sling splint. The model shown is for the left leg.

A B, J I = 5 in.; B C, H I = 30 in.; C D = 15 in.; H G = 13 in.; D E = 7$\frac{1}{2}$ in. (cord of the arc); E F = 10 in; C H = 8 in.; B I = 5 in.; P = 22 in.; Q = 31 in.; K L, Board, 34 in. by 9 in.; M N O, Flat steel support; R. Pulley-wheel. The bend of the splint at C and H is 11 in. above the board.

This appliance can be placed on any firm mattress, on the deck of a ship, or on a stretcher, equally as well as on a hospital bed. It will serve perfectly well for the treatment of the fractured thigh for two or three weeks. At any period during this time extension may be applied by transfixion without moving the limb from its cradle. This is done simply by screwing on two angled uprights (as shown in *Fig.* 128) which bear a pulley-wheel. The latter is sufficiently high to allow a direct pull in the line of the femur and to take a 20-lb. weight between the uprights. In this position the weight hangs snugly, and can be further secured by a loop of rubber tubing, so that the patient can readily be moved with the complete apparatus. This is of great value not merely in allowing the patient to be transported, but in enabling him to be taken to the *x*-ray department in order that the result of the extension can be tested from time to time.

Treatment of Gunshot Fractures of the Leg in Hospital.—Once the patient is in hospital, the leg should be placed on the cradle splint, if this has not already been used in transport. If the wound is severely infected, then two courses are open. It can be simply left on the cradle splint mentioned, or it can have an adhesive plaster extension applied to it as shown in *Fig.* 24. If the wound infection is not serious, or when it has been overcome and healing is taking place, then undoubtedly transfixion for the femur, and weight or elastic extension for the lower leg, is indicated. If the femur is transfixed within a week or two of the injury, a weight of 16 lb. will produce full extension—that is, about three-quarters of an inch over-extension—within a few days, and the further progress will be smooth and satisfactory. After about four weeks, or a less period in benign fractures which are very oblique or near the lower end, the transfixion is removed. If the splint referred to above has been used, the weight-supporting uprights are unscrewed, and the limb is allowed simply to remain in the double inclined wire cradle for another two weeks. The joints are kept semiflexed, extension is maintained, and the joints can be exercised as soon as necessary, whilst at any time the sling which ties the limb to the splint can be removed in sections for the dressing or irrigation of the wound.

The Treatment of the Wound itself must be our first care after the limb has been arranged on the splint. If inflammation and the presence of a discharge show that the wound is infected, it is to be thoroughly opened up and cleaned with the most painstaking care at the earliest possible moment. Foreign bodies are removed, with all dirt and bone débris. Free drainage is essential, but is by no means easy of attainment. Long ago surgeons recognized that a tube placed in the abdomen will not drain the entire peritoneal cavity, but only the local area wherein it lies. It is not sufficiently recognized that the same principle applies to septic wounds of the limbs. If a large tube or several split tubes be placed right through a leg, the pus will still collect in the intermuscular planes and track along to dependent places.

Gauze packing is open to the objection that the gauze soon becomes filled with coagulated lymph, and that it then acts rather as a cork than a drain; and, further, it is excessively painful to remove and reinsert this at frequent intervals.

In bad cases of infection it is absolutely necessary to provide a large wound at the most dependent part of the limb at the back of the thigh, for instance when the leg is suspended, and also to arrange this wound so that it naturally remains gaping open quite independently of tubes. This can only be done by a *transverse* incision of the muscles. If the hamstring or adductor muscles be freely divided across their fibres, the resulting wound will remain widely open as long as the deep suppuration continues. If this division of the muscle be made with discretion, there is no fear of any permanent muscle defect, as it is never necessary to divide more than a moiety of its thickness.

An open gaping wound having been provided at the lowest point in the limb which can be connected with the injury, a large split tube is inserted, or loose gauze packing, a combination of the two being the best.

So long as severe sepsis is present in the wound, and until healing is manifested by a cessation of discharge, odour, and high temperature, and an appearance of granulations, there is one method of treatment which so far excels all others that it should always be adopted. This is the use of continuous irrigation. Directly the wound has been lightly filled with gauze and the drainage tube inserted, the nozzle of a douche-can is placed in the meshes of the gauze and lightly fixed there by a suitable bandage. Then a constant stream of a weak antiseptic, such as permanganate of potash, is made to run in at the rate of about one quart an hour. A very little dexterity on the part of the nurse, and a very little experience, will enable her to manage this quite well in such a way that a waterproof sheet conveys the lotion to a bucket at the side of the bed.

If on the other hand the wound has closed, or if it is healthy in appearance and there are no signs of local or constitutional infection, it should be treated by a simple dressing. It is very unwise to open up a simple wound in order to remove a bullet or bits of bone, because by doing this a large wound will be made, and the comminuted bone will be so disturbed as to increase greatly the risk of loss of its fragments by infection.

The Treatment of Loose Bone in Comminuted Fractures. —There is a most unreasonable and reprehensible desire on the part of nurses, and even of surgeons, to pull out any piece of loose bone that may be present in the tissues. Argument on this subject is hardly necessary. Only reflection is needed to remind us that the normal fate of comminuted fragments of bone is to be finally consolidated in callus, to the formation of which they each contribute a part. The fact that the fracture is open or septic does not alter this, although certain fragments may die and be cast off in the course of repair. It is almost impossible to be certain that any scrap of bone is non-viable, and if it retains any vascular connection with the main bone or soft tissues it certainly ought, when the fracture concerns the shafts, to be left in place. About the actual death of certain fragments of bone in a septic wound which are loose, bare, and connected with no vascular supply, there can be no doubt. These only should be removed, and if there is the slightest doubt about the matter, then they should be left. This is a very different thing from using a pair of sequestrum forceps and seizing upon any piece of bone which can be felt in the wound and twisting it out. It is this latter practice which cannot be too strongly condemned.

If a piece of bone comes away from the wound, I should certainly not replace it, because I believe that it will not retain its vitality in the presence of marked sepsis.

If the fracture is in the neighbourhood of a large joint, then I think we ought to be much freer in the removal of loose bone. Round the shoulder, ankle, and elbow, in particular, these loose fragments are liable to cause a callus excess which will tend to lock the joint, and their removal will not lead to the delayed union and weakness which results from such treatment when applied to a fracture of the shafts of the long bones.

The Immediate Operative Fixation of Gunshot Fractures. —One would hardly have considered it necessary to discuss this subject, since in recent years it has been rightly and universally held that the presence of serious sepsis was an absolute contra-indication to the operative fixation of fractures. But in the stress of circumstances some have unfortunately been bold enough to challenge this rule. They have been distressed at the intolerable pain endured by cases of open fracture of the femur or tibia, and have sought to lessen this by screwing on plates to the fragments of the bone which lay invitingly exposed in the wound.

We have become more or less familiar with this practice, for these patients have been sent back to this country later, and we have witnessed the results. Not only have we unwillingly had to take a share in this treatment, but we have read with some surprise articles extolling it by those who have carried out the first stages.

The argument runs : These cases are terrible—every day the patient is submitted to torture in the dressing of his wound, whilst in the wound can be seen the bones, which can readily be plated; the fixation of the plate 6 to 10 inches long by six or eight screws is easy, and when this has been done the patient is much better, the screws hold splendidly in spite of the misinformed persons who aver that screws quickly loosen their hold on bones, and the patient is much more comfortable, his tortures on dressing being at an end ; patients so treated can soon be moved home. There the matter is assumed to end.

I give one example out of many which have reached this country, in order to finish the story, and to put the matter in a proper light.

A soldier was wounded in France, sustaining an open fracture of the left tibia and fibula. The tibia was plated by a 6-inch heavy plate with six screws, and he was sent to the 2nd Southern General Hospital in Bristol. He had a large open wound of the leg, and the whole length of the plate was exposed. At first he was fairly comfortable. But soon his ease gave place to pain, and the sepsis assumed a more serious character. It was evident that the whole portion of the shaft of the tibia to which the plate had been attached had necrosed, and was being separated slowly from the living bone above and below by septic ulceration. His condition had shortly become so serious, both in regard to septic absorption and pain, that he begged to have his leg amputated, and this was done. The specimen is shown in *Fig.* 129. It will be noted that though the tibia has suffered necrosis in all the part on which the plate is fixed, the fibula has undergone natural repair.

While it would be unjust and ungenerous in the extreme to single out such a case for censure when it is considered how skilfully a difficult condition had been dealt with, and how, to the surgeon who did the operation, immediate success seemed to have rewarded his efforts; yet it is necessary to hear the whole of the story in order to judge of its first chapter. And it is imperative to condemn a practice which can produce such a result, even if it is only an exceptional one.

If out of a series of ten cases of open plating of septic fractures, only one ends in the loss of the limb, that is quite enough to prove the method to be unjustifiable; and I doubt much, if all these cases could be followed up, whether it could be shown that ultimate success resulted in even a bare majority.

It has been claimed that the fact that the screws hold firmly in the bone is evidence that the method is good and reliable. The specimen figured, from the case I have referred to, is interesting in this connection. In it the screws are absolutely firm, and it would have been easier to separate the dead bone from the living than to have removed the plate from the shaft to which it had been screwed. But the crux of the whole matter is that the bone to which the plate is screwed is dead, and therefore quite incapable of those vital changes by which living bone becomes rarefied and softened round tightly-driven screws.

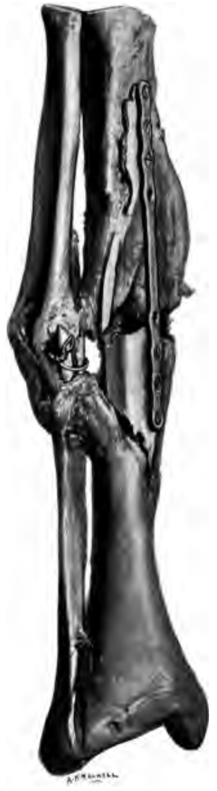
Fig. 129.—Drawing of the leg bones of a case of gunshot fracture. The limb had to be amputated on account of sepsis. It is seen that exactly those parts of the bone which hold the plate have necrosed, whilst apart from these areas the tibia exhibits good reparative power. While the fibula is much less necrosed, here again necrosis is limited to the area of operative interference.

A bone lies exposed in a septic wound. In order to apply a long plate to this, two things are necessary. First, the wound must be greatly enlarged, and the sepsis thereby extended; and secondly—and this is even more fatal—the bone must be drilled in six or eight places, and the sepsis thereby carried into its marrow cavity. This seems to me quite unjustifiable, both on theoretical grounds, and also because of the disasters of which we have been witnesses.

The chief excuse for operating upon and plating recent septic fractures is to immobilize the fragments and so to make both dressing and transport easy. But both these ends can be accomplished by means of one of the sling-splints already described.

CHAPTER IX

ON UN-UNITED FRACTURES

DELAYED union and non-union, the formation of fibrous synostosis or a false joint, depend upon several different causative conditions, for the proper comprehension of which it is necessary to understand the stages of natural bone repair.

The first event in this process is the pouring out of cells from the broken bone and from the torn tissues to form granulation tissue, which by calcification becomes callus. Then the whole mass of callus gradually becomes firmer by the deposit of more lime salts; the open network of trabeculæ grows closer and more dense. In the meantime the bone ends undergo an opposite transformation. They become canalized by cellular and vascular erosion, and the dense bone grows almost spongy in texture, until its consistence is the same as that of the ossified callus. Then, when homogeneity between rarified bone and ossified callus has been attained, the parts which lie in the line of the greatest stress become more and more dense by a filling up of the vascular spaces with bone, whilst the callus which lies outside the lines of stress is gradually absorbed. I have not dealt with the fact, which is generally unrecognized, that in the process of conversion of the original granulation tissue into bone, there is usually a stage of cartilaginous transformation. We do not know enough about the rôle of cartilage in the repair of human fractures to enable us to assign thereto any definite place in the causation of non-union.

For the sake of simplicity, we may say that the union of a fracture requires:—(1) The formation of granulation tissue around each broken end; (2) The fusion of the granulation masses with one another; (3) The rarefaction of the bone ends; (4) The ossification of the callus granulations. Delayed union or non-union may be caused by interference with any one of these factors.

Interference with the Laying Down of Granulation Tissue or Pro-Callus.—The granulation tissue which is the precursor of callus is laid down by the open ends of the vascular canals of the bone, and to some extent also by the deep layer of the periosteum where it is torn from the bone. But the periosteum acts rather as a limiting membrane than as a matrix of new bone. If it is left tightly adherent to the bone, then at that surface no pro-callus granulations appear. Similarly, a fringe of periosteum lapping over the end of the bone will inhibit at that point the formation of callus.

This is shown in the accompanying diagram (*Fig.* 130). In A the bone has been broken and the periosteum completely torn through, remaining attached to each fragment. No callus granulation can occur except at the ends of the bone, which are separated from one another. In B the periosteal sleeve is intact, and the fragments lie within it. In the angles x x callus is poured out, and rapid union occurs. This relation of the periosteum to callus formation is abundantly demonstrated by such experimental specimens as those shown in *Fig.* 58.

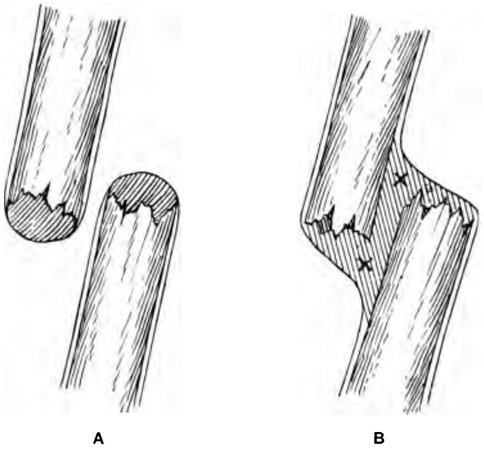

Fig. 130.—Diagram illustrating the relationship between the periosteum and callus formation.

Adhesion of the periosteum, therefore, and interposition of periosteum and fascia between the fragments, will account for non-union. The humerus, probably, is often subject to this factor. In that bone the periosteum is very difficult to strip off, especially just on a level with the insertion of the deltoid.

It is difficult to be certain of any other factor which will prevent the formation of pro-callus. Mobility of the fragments may cause non-union, not by preventing callus formation, but by interfering with the union of callus masses. Simple immobility and absolute fixation seems to be a factor in the case of the skull bones, where callus and union are both usually absent; but it is hardly fair to compare the skull bones with those of the limbs.

It might be thought that mere want of vitality in the bones would prevent pro-callus formation; but against this is the fact that fractures in very old people show no special tendency to non-union.

A want of vascularity of one fragment may occasionally account for non-union. The only case where this is probable is in the complete separation of the head of the femur.

Failure of Union of the Callus Masses.—*Fig.* 59 illustrates this condition very well. It can only occur when there is gross separation of the fragments, with free mobility. It probably accounts for the majority of cases of non-union with pseudarthrosis in animals, and also for a few cases in human subjects in the humerus and femur where these conditions prevail. There is here no failure of pro-callus or of callus formation, but each fragment forms its own callus, which undergoes the usual transformation into calcified material—cartilage or bone—without uniting with the neighbouring callus mass. The constant mobility causes a fluid exudation like synovial fluid between the callus masses, whose outer layers quickly become fibrous or fibrocartilaginous.

It is sometimes objected that free mobility cannot account for non-union, because fractures of the ribs, which are never wholly immobilized, never fail to unite. But this mobility of the ribs is quite a different thing from the mobility of the femur in an animal which dangles its leg all the time, or of a human humerus with a hanging arm. In the ribs the mobility is of a very restricted kind, and the ends of the bone, being still enclosed within a raised sleeve of periosteum, are in the most favourable condition for union.

Conditions of Abnormal Density either of the Bone Ends or of the Callus.—The proper and firm union of the bone depends upon a regular sequence of changes in the consistency of both the original bone and the callus. At first the bone must rapidly become porous, in order that it may pour out sufficient callus. Later, the canaliculi of the bone become filled up by new bone formation, and it is then more dense than it was originally. If this condensation of the bone occurs before the callus has become mature, the latter loses its chief blood-supply; the ends of the bones become eburnated, and not only do they not unite, but they will not unite however they are fixed, because the chief callus matrix is sealed up. This will be the final condition of many cases of non-united fractures, and its importance cannot be too much insisted upon: for unless understood and corrected, operations undertaken for non-union will always fail.

Wide Separation of the Fragments.—Callus, or pro-callus, like granulation tissue elsewhere, cannot extend more than a very limited distance from its own base or seat of origin. If a large gap is made in the soft parts by a burn or trauma, we know that though this may become lined by granulations, these cannot fill a large space, and that eventual healing occurs by a pulling together of the edges of the wound and a drawing down of the surface edges towards the level of the base. Neither granulations nor scar-tissue can form more than a thin layer a quarter or half an inch thick. This is probably due to the fact that when granulation tissue has reached a certain thickness, the vessels in its deeper layers become constricted by a conversion of the cells into contracting fibrous tissue. But whatever the explanation, the fact is undoubted that in the mammalia, contrary to what occurs in some reptiles and invertebrates, there is no capacity for tissue or organ reproduction after loss, and that the tissues of repair can only extend for a short distance from the matrix of the injured part.

This applies exactly to bones, at any rate in adults. That is to say, if a piece be taken out of the shaft of one of the long bones, and the remaining portions be prevented from coming into contact, each of the fragments will pour out callus from its cut end until a small cap has been produced; this callus will then ossify, and no further change will occur to bridge over the gap.

Hence it is that a loss of substance involving a definite gap in a bone shaft will inevitably lead either to very great shortening, if the ends are brought together, or to non-union.

The objection may be raised that this is quite contrary to what occurs in infective necrosis, when the removal of a large part of the necrosed shaft is quickly followed by regeneration. But here the conditions are different. Before the sequestrum separates or becomes necrosed, there is poured out from its surface a layer of bone cells which adhere to the periosteum. When the dead bone is taken away, there is left a tube of periosteal bone, from which the shaft is re-formed. These infective conditions, moreover, occur in young subjects in whom there is much greater capacity for bone regeneration than in adults.

The inability to replace a loss of substance in the shaft of a long bone is one of the reasons for not removing loose fragments in cases of gunshot wounds.

Summarizing the above, the chief causes of non-union are: (1) Interposition of soft parts, particularly the adherent periosteum; (2) Unrestricted mobility; (3) Eburnation of the ends of the bone before maturity of the callus; and (4) Loss of bone substance.

OPERATIVE TREATMENT.

Hitherto the operative treatment of cases of un-united fracture has been somewhat empirical. The bone has not united, and therefore it is artificially joined by a plate and screws. But this is quite unsatisfactory. We must aim at true bone union—not plate union; and as the conditions are such that bone union will at the best be slow, we must carry out an artificial union which will hold firmly for a long time.

Of late years it has been recognized that the main thing to be aimed at is the stimulation of new bone growth, and with this object in view bone-grafting has been introduced; it is often, however, carried out in a manner which cannot succeed in its object, because the graft is so loosely inserted that it cannot become vascularized before its own vitality is lost.

There are three methods to be considered in the operative treatment of un-united fractures: (1) *Efficient fixation;* (2) *Stimulation of callus production;* and (3) *Bone-grafting.*

1. **Efficient Fixation.**—In discussing the general principles of operative treatment, it has been pointed out how the ordinary screwing of plates to the outside of bones is apt to give way before vital union has occurred. This applies with much greater force to the present group of cases. Vital union is very slow, and therefore it is useless to employ any fixation which cannot hold firmly for an indefinite time. The ends of the bones must be transfixed, and a single plate—or better still, double plates—bolted in place; these are put on subperiosteally. The raising of the periosteum and the boring of the bones will provide an excellent stimulus to callus production.

In the bones where non-union occurs most often, viz., the humerus and the tibia, the double bolted plate is quite readily applied.

2. **Callus Stimulation.**—In almost all cases of delayed union, the ends of the bone have become eburnated (as in *Fig.* 51). Their vascular channels have been closed by the laying down of new bone, and in this condition they can only produce callus—or in other words, vascular granulation tissue—very slowly, if at all. This dense layer of bone must be cut through in order to expose the vascular bone and allow the granulations to spring out of it.

To cut a thin layer from the bone ends will reduce the length of the bone, and it will only get at a small superficial area of the bone tissue.

If, on the other hand, the ends of the bone are cut with a saw parallel to their long axis, this will tap a large area of bone-producing tissue without sacrificing any length (*Fig.* 131, A).

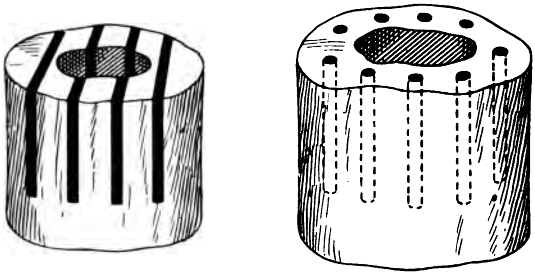

Fig. 131.—Methods of opening up channels for callus production in eburnated bone ends. A. By transverse saw-cuts; C. By axial drilling.

Wildey* has recently made the suggestion that the ends of the bone should be drilled in their long axis (*Fig.* 131, B), and he has brought forward cases where union has taken place after this proceeding when it had failed after other methods.

There is, however, this point in favour of the saw-cuts over the drilling—viz., that the former extends the callus-bearing area on to the subperiosteal surface of the bones, whereas the latter only affects the ends.

I believe that if the following three points are carefully carried out, there will be few cases in which union will fail to occur; (1) The freeing of the ends of the bone from the soft parts, particularly from adherent periosteum; (2) The longitudinal sawing or drilling of the eburnated ends of the bone; and (3) The efficient fixation by means of double bolted plates.

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* *British Journal of Surgery*, Jan., 1915.

3. **Bone-Grafting.**—The original idea in bone-grafting was that the site of fracture was for some reason or other deficient in callus production, and that if a freshly-taken piece of bone was introduced into the fracture area, it would act as a centre of bone growth which would knit the fragments together.

I am aware that on the subject of bone-grafting there is still much controversy as to the rôle of the graft, so that it is impossible to be dogmatic about it. But I think that there is a general consensus of opinion upon these points: (1) That even under the most favourable conditions a large part of the graft dies—that is, its living cells disappear; (2) That the graft acts rather as a scaffolding for new bone than as a source of it; (3) That if the vascular conditions be favourable, some of the cells of the graft do survive, and become a source of new bone.

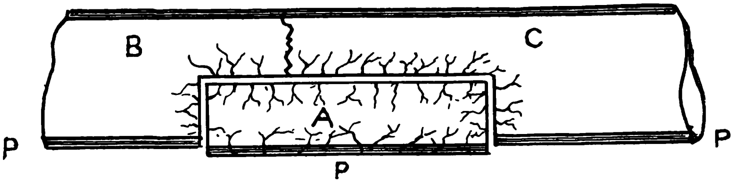

Fig. 132.—The vascular supply of a bone-graft. A. Graft; B. C. The fragments of the fractured bone; P Periosteum.

Let us consider for a moment what are the vascular conditions in a piece of grafted bone (*Fig.* 132). When first grafted it has no blood-supply. The only channels by which this can be established are through the open mouths of its own Haversian canals, or by adhesions which its periosteum acquires to the surrounding bed of living tissues. If a new blood-supply be not established quickly, the orifices of its vascular canals will become filled by fibrous tissue and its own essential cells will perish. Now in order that a vascular bridge should be quickly established between the bone-bed and the graft, it is necessary that the latter should be immovably fixed to the former, otherwise the capillary loops which sprout out from the bed will not be able to penetrate the Haversian canals of the graft, but will be torn by mechanical action. A good layer of periosteum and fascia on the outside of the graft will greatly facilitate the vascularization of the bone, because it will act as a medium of anastomosis between the vessels of the living tissues and those of the graft.

the bone has to bear. The bone plate may be cut out in the form of a quadrant by means of the special circular saw, and in this shape it gives great longitudinal rigidity.

The principle of the taking of a long fragment from one piece and a short fragment from the other, and then reversing them, is the same as before, and when the fragments are in position, they are bolted in place.

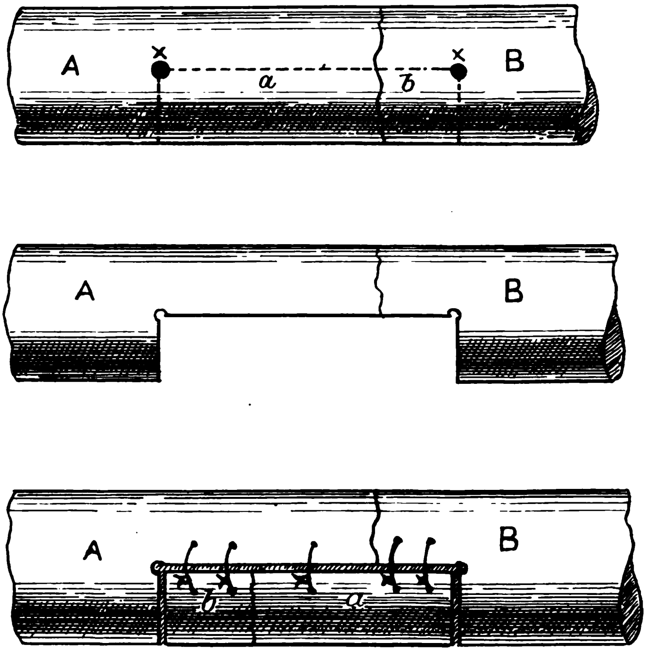

Fig. 133.—Bone-grafting by the cutting of unequal pieces from the fragments of a fracture, and then reversing them. In the upper figure the fragments A and B are bored at points x x, and cuts made so as to take a piece *a* from A more than twice as long as the piece *b* from B. In the middle figure these pieces are removed. In the lower figure the piece *a* has been placed in the angle of B, and the piece *b* in the angle of A, and there sutured by wire sutures.

In both these methods it will be noticed that the long cuts (at least three inches long for big bones) will provide a large fresh surface from which new bone cells can rapidly exude.

iii. *The Use of a Graft from Another than the Fractured Bone.*—In most cases this is quite unnecessary, and only involves a larger and more difficult operation. The non-union of the

But whatever conditions are obtained for it, it is perfectly certain that the graft acts mainly as a splint, i.e. as a passive supporting agent, and that any proliferation of new bone from it takes place quite slowly.

This is quite different from the conception that has been formed of a bone-graft by many who have used it. They have been content to lay an ill-fitting bit of bone inside the marrow cavity of the fracture, or tie it on to the outside of the bones by catgut, and then expect that it will act as a luxuriant centre of new bone growth.

With a bone-graft it is more necessary than ever to secure absolute firmness and rigidity of fixation, for we are dealing with conditions in which natural healing is slow, and moreover the graft cannot take on new growth unless it is very firmly united to its bed.

Whatever method of bone-grafting be used, it is necessary to make an extensive exposure of the bone tissue of the fracture by some kind of sawing or drilling, because, as I have said, the old bone after all must be the chief source of callus. In many cases mere sawing of the fragments longitudinally is all that is required, and if grafting is done, it is still necessary to saw the fragments.

Three methods of using a bone-graft in the union of fractures are described, each of which has given good results, both experimentally and clinically.

i. *Longitudinal Splitting of the Bone, with Reversal of Fragments* (*Fig.* 133).—This is suited to the small and superficial bones. It is easily carried out on the ulna and the tibia. The bone is exposed, correct alinement is obtained, and the fragments are held in correct position. Then the bone is pierced at the holes x, x, by a drill which makes a hole large enough for the special fret-saw to be used ; *a* is twice as long as *b*. The saw cuts transversely into x and x from the surface, and then along the line x x, approximately the middle of the thickness of the bone. Then the pieces *a* and *b* are taken out, *a* being twice as long as *b*, and put back so that *a* lies next to *B* and *b* next to *A*. The piece *a* thus acts as a bridge across the line of fracture. A number of drill-holes are made through the bone and through the fragments, and the whole is tied up perfectly firm by wire loops.

ii. *The Bolting of a Bone-graft.*—This method is better than the last for the larger bones—the femur, humerus, and tibia—because the firmer fixation is more suited to the stress which the bone has to bear. The bone plate may be cut out in the form of a quadrant by means of the special circular saw, and in this shape it gives great longitudinal rigidity.

The principle of the taking of a long fragment from one piece and a short fragment from the other, and then reversing them, is the same as before, and when the fragments are in position, they are bolted in place.

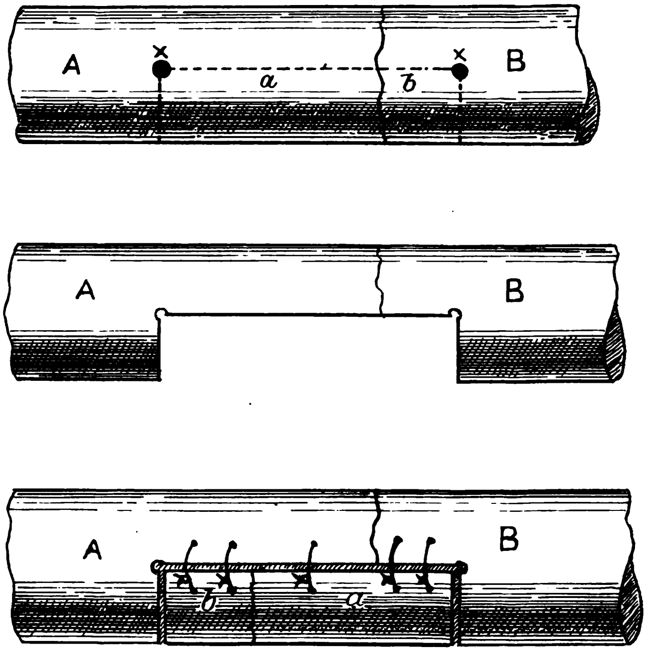

Fig. 133.—Bone-grafting by the cutting of unequal pieces from the fragments of a fracture, and then reversing them. In the upper figure the fragments A and B are bored at points x x, and cuts made so as to take a piece *a* from A more than twice as long as the piece *b* from B. In the middle figure these pieces are removed. In the lower figure the piece *a* has been placed in the angle of B, and the piece *b* in the angle of A, and there sutured by wire sutures.

In both these methods it will be noticed that the long cuts (at least three inches long for big bones) will provide a large fresh surface from which new bone cells can rapidly exude.

iii. *The Use of a Graft from Another than the Fractured Bone.*—In most cases this is quite unnecessary, and only involves a larger and more difficult operation. The non-union of the

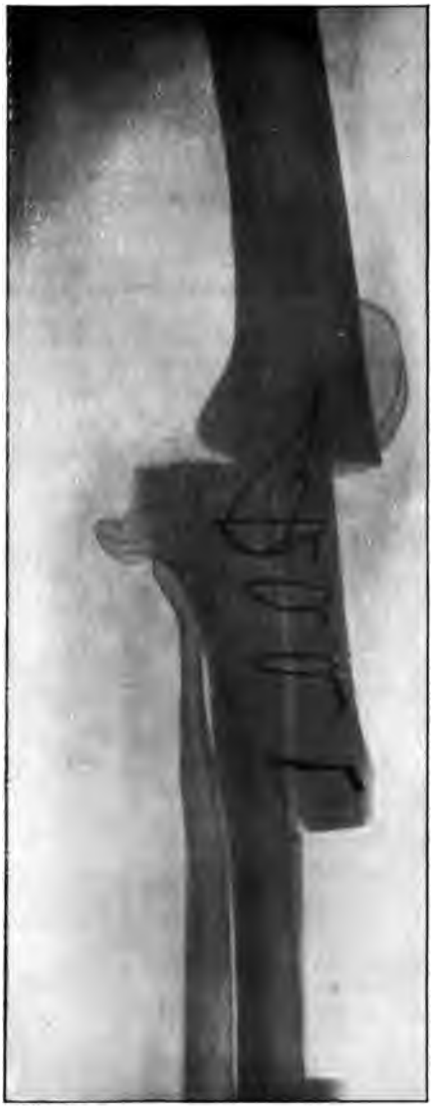

Fig. 134.—Bone-graft for fixation after excision of the knee. The graft has been cut from the tibia and reversed, its small end being driven into the femur, and its larger end sutured to the tibia. The same method may be used in uniting a fracture.

fracture is not due to a special fault of the particular bone, but merely to an eburnation of the fractured ends and a closing in of all the callus-producing tissue.

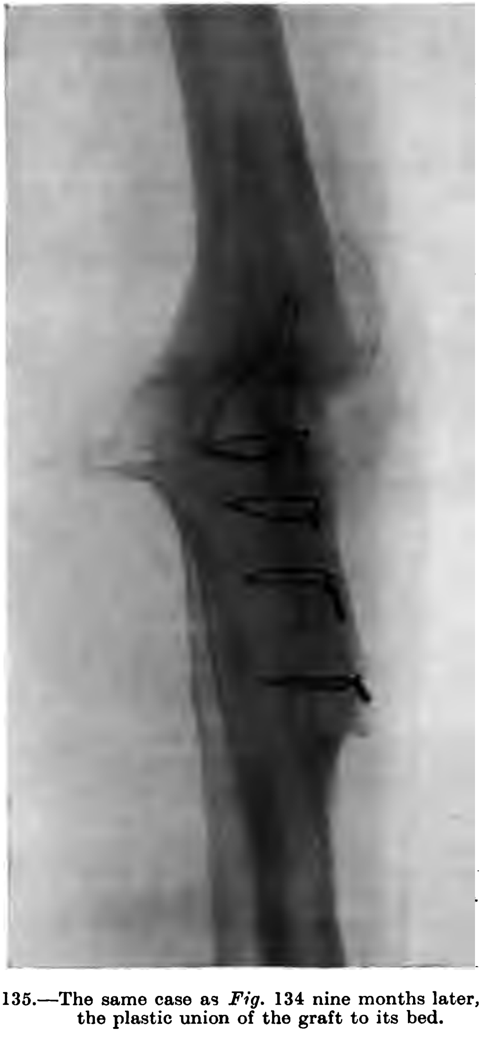

Fig. 135.—The same case as *Fig.* 134 nine months later, showing the plastic union of the graft to its bed.

But there are some cases where there has been actual loss of bone substance, due perhaps to necrosis, or to the destructive results of gunfire. In these cases only should fresh bone be taken from elsewhere, and the anterior border of the tibia affords the best source of supply.

If the humerus or femur is to be repaired, the new graft may be driven into one fragment as a peg, and secured to the other fragment as an inlay, in the manner shown in *Figs.* 134, 135.

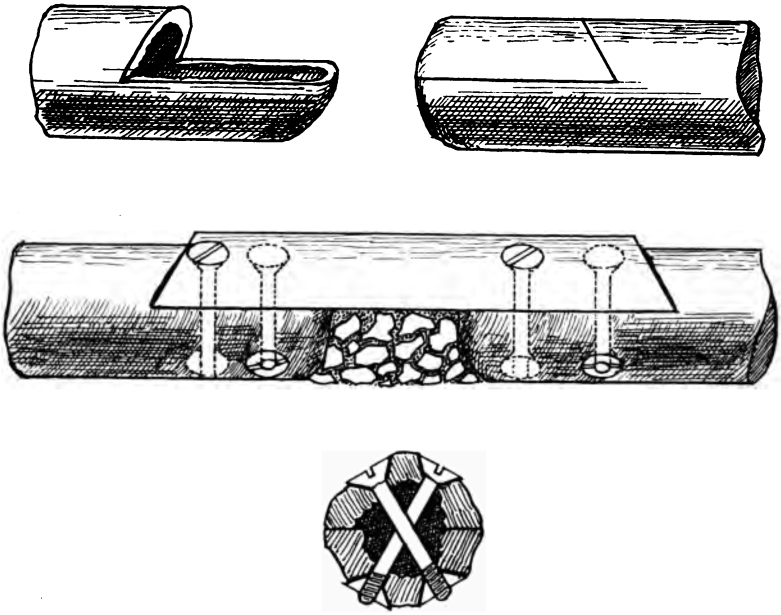

Fig. 136.—In the upper figure the bone ends are shown cut for the reception of the graft. In the middle figure the graft is seen bolted in place, the pieces of bone cut from the original fragments being divided up and placed in the gap. The lower figure shows the junction of the graft and the bone in transverse section.

But if grafting has to be undertaken not only to unite a fracture but to make good a considerable loss of substance, it is better to carry out a more elaborate operation, as illustrated in *Fig.* 136. The fragments to be united, although separated by a gap, will have nevertheless been drawn close together by muscular traction. It will be necessary, therefore, to separate them, and this is best undertaken by a preliminary extension. The lower end of the distal fragment is transfixed and pulled upon by a full weight extension for a few days before operation.

The first part of the operation will consist in placing a transfixing-pin in the upper fragment, and by means of the double transfixion apparatus the fragments are adjusted and fixed as may be desired. The graft is cut from the front of the tibia, taking about one half of its thickness, and carefully preserving the periosteum. The ends of the graft are cut with an acute angle at the long sawn surface.

The fragments of the fractured bone are now freely exposed by a long incision, with thorough muscle retraction. Each end is sawn down its long axis for about one inch, and by oblique cuts half the thickness of the bone is removed. The oblique cuts of the fragments and the acute angles of the graft are designed in such a way that when extension is withdrawn the graft tends to be locked in its place.

An exact calculation must be made beforehand as to the amount to which shortening is to be made good. For example, there is 3 inches of shortening in a thigh, and the *x* rays show a 1½-inch gap still remaining between the fragments. To produce full restitution of length in such a case the graft will have to be $3 + 1\frac{1}{2} + 1 + 1 = 6\frac{1}{2}$ inches in length, and it is better to cut it a little longer. Generally it will be impossible to fully make good the shortening, and probably a 5-inch graft with each end inlaid for 1 inch, giving a 3-inch bridge, with a 1½-inch gain in length, is the most that can be achieved. When the graft has been cut the right length, and the ends shaped to receive it, a final extension is made until the graft can just be dropped into its place. Then two or three holes are drilled right through the overlapping graft and bone end, and these are fixed by bolts and nuts in different diameters of the bone.

It is absolutely essential that the fixation of the graft should be firm and rigid, in order that it may not only act as a plate, but may unite readily to the old bone ends. The periosteal surface of the tibia remains outwards, and the periosteum attached to it forms an invaluable medium for new vascular connections with the surrounding soft tissues. I think it has been fully demonstrated that bone grafted with its periosteum attached, grows more certainly and more quickly than bare bone. This is not due to osteogenesis by the periosteum, but to the fact that the connective tissue of the periosteum readily grows to the surrounding soft tissues, and so establishes a vascular supply to the graft.

The half-ends which have been sawn out from the old bone are not discarded, but are broken up into small pieces, which are laid in the trough between the medullary aspect of the graft and the ends of the old bone. The latter are pierced by multiple drill-holes to allow fresh callus exudation. The muscles are sewn round the reconstituted bone very carefully, so as to enclose it in a vascular tube.

It is wise to leave the double transfixion apparatus in place for two or three weeks. This will not only ensure the bones being kept in good position, but will act as a most efficient splint in preventing the new union being broken down either by movement or muscular tension.

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